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EFFECT OF CARBON TO NITROGEN RATIO ON ACTIVATED SLUDGE SUBSIDENCE AND DEWATERING CHARACTERISTICS

Anthony Geinopolos

Envirex Incorporated

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EFFECT OF CARBON TO NITROGEN RATIO ON ACTIVATED SLUDGE SUBSIDENCE AND DEWATERING CHARACTERISTICS

by

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Project 11060 DSE
Program Element 1BB043

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ABSTRACT

A field investigation was conducted to determine the effect of organic carbon to ammonia nitrogen ratio (C/N) on activated sludge subsidence and dewatering characteristics. C/N changes were made on one of two full-scale activated sludge systems of a pulp and paper mill. Bench scale tests were used to evaluate and compare the effect on solids subsidence characteristics. Pilot flotation thickening and pilot vacuum filtration tests were performed to evaluate and compare the effect on dewatering characteristics.

It was determined that when both the "control" and "test" activated sludge systems were nitrogen nutrient deficient, the solids subsidence and dewatering characteristics were similar and unaffected by C/N changes. On the other hand, when both systems were nitrogen sufficient, it was indicated that the C/N ratio had an appreciable effect on the solids subsidence and compaction properties.

The project objectives were not fully achieved because the available project funds to do so had been exhausted. Because of the inability to obtain additional financial support for the study program, the project was terminated.

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Two activated sludge systems were operated with nitrogen deficient paper and pulp mill wastes. Control of the organic carbon to ammonia nitrogen ratio was applied to study the resulting characteristics of the waste activated sludge. Pilot scale air flotation and vacuum filtration tests were conducted. A sludge that resulted from a waste with a carbon to nitrogen ratio of 15:1 was found to have the best dewatering characteristics.

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This investigation was carried out by the Environmental Sciences Division of Envirex Inc., Milwaukee, Wisconsin. Mr. Anthony Geinopolos directed the work and is the author of this report. Implementation of the field operational test plan, including setting up the field laboratory, data collection, analytical determinations, pilot plant operation, and data analysis was conducted by Mr. John Pernusch and his field staff. Their efforts and diligence were essential to the collection and evaluation of the data presented. Their contribution is sincerely acknowledged.

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SECTION I

CONCLUSIONS

1. When the "control" and "test" activated sludge systems were operated under similar operating conditions, including C/N ratio, solids were produced from both systems having similar subsidence, thickening, and filtration properties.

2. When both activated sludge systems were nitrogen nutrient deficient, the solids subsidence and dewatering characteristics observed were similar and unaffected by C/N changes investigated.

3. When both systems were nitrogen sufficient, it was indicated that the C/N ratio had an appreciable effect on the solids subsidence and compaction properties.

4. The parameter, C/N ratio, appears to be a reliable and effective control measure in the activated sludge treatment of nitrogen deficient wastes. However, each application should be investigated on its own merits.

5. At the Scott Paper Co., Mobile, Alabama, it was found that:
   a. Existing TOC analyzers provide a rapid and reliable method for measuring the organic carbon content of the wastewater.
   b. Because of interferences encountered, it was concluded that the distillation-titration method was the most accurate for the measurement of ammonia of those methods investigated.
   c. A C/N ratio of 30 used resulted in an activated sludge having relatively poor subsidence, thickening and filtration properties.
   d. The optimum C/N ratio appears to be equal to or less than a value of 15.

6. The project objectives were not fully or conclusively achieved because the available project funds to complete the project had been exhausted. The study program was terminated because of an inability to obtain the necessary financial support.

SECTION II

RECOMMENDATIONS

The results obtained from this study have indicated that C/N ratio is a reliable operational tool which may be effectively used in the activated sludge treatment of nitrogen deficient wastewaters. However, this investigation did not fully explore or describe the effect of C/N ratio upon the subsidence and dewatering properties of activated sludge.

Therefore, it is recommended that the work begun in this study be further extensively continued to confirm the promise of the use of the C/N ratio as a treatment plant operational tool. It is felt that the results of continued study will lead to information which will be of value in increasing treatment process efficiency and in decreasing the cost of the total waste treatment process. Specifically, the potential value lies in the areas of final clarification and of sludge handling and disposal.

SECTION III

INTRODUCTION

One of the by-products of waste treatment is waste sludge, which contains, in more concentrated form, the objectionable contaminants removed from the raw waste by treatment. Handling and disposal of this by-product is one of the most important and most troublesome problems associated with the design and operation of waste treatment facilities.

Wastewater and sewage treatment plants in the United States currently devote from 25 to 50 percent of their capital and operating funds in the handling and disposal of waste sludges, and it is estimated that the volume of waste sludges such facilities must cope with will increase 60 to 70 percent in the next fifteen years. By far, the major portion of the increased sludge volume expected will be obtained from secondary treatment sludges, which are most difficult and expensive to handle and to treat.

It is evident from the above brief discussion that research into sludge handling has great potential value for increasing the efficiency of solids disposal, thereby increasing the process efficiency and decreasing the cost of the total waste treatment process. Moreover, it is apparent that the greatest benefit which may be derived from sludge handling research lies in the investigation of means for significantly reducing secondary treatment sludge volumes for subsequent treatment and disposal.

Published literature, bench-scale laboratory studies, and operating data from activated sludge waste treatment plants indicate that a cause/effect relationship exists between the carbon to nitrogen ratio in the waste flows and the subsidence and dewatering characteristics of the sludges resulting from activated sludge treatment of these wastes. Published literature regarding this relationship is also available, but is based solely on the results of bench-scale laboratory tests which cannot duplicate the types and numbers of variables present in an operational treatment plant. As a result, little is known about the mechanisms which are involved in the relationship, and the engineering knowledge required to apply it to operating plants is essentially lacking.

To ensure a high level of confidence in the data obtained from an investigation of this problem, it was felt that evaluations must be made under conditions of full-scale operation. As a result, this research study was conducted by the Ecology Division of Rex Chainbelt Inc. utilizing the waste treatment facilities of the Scott Paper Co. located in Mobile, Alabama. The objectives of EPA/WQO Contract No. 14-12-820 were as follows:

1. Determine how the subsidence characteristics of activated sludge are affected by the carbon to nitrogen ratio of the waste treated.
2. Measure the effect of the carbon to nitrogen ratio on the thickening characteristics of activated sludge.
3. Determine how the carbon to nitrogen ratio affects the dewatering of activated sludge by belt vacuum filtration.
4. Conduct an engineering evaluation of the above determinations and establish a recommended optimum carbon to nitrogen ratio for the operation of the Scott Paper Co., Mobile, Alabama activated sludge treatment plant.

Basically and briefly, the technical approach used in this study was to operate a portion of the secondary treatment facilities at the Scott Paper Co., Mobile, Alabama under conditions covering a wide range of carbon to nitrogen ratios, and to quantitatively study the effects of these ratios on the subsidence, thickening, and filtration dewatering characteristics of the activated sludge. To provide bases for comparison, another portion of the secondary treatment facilities was operated under constant, normal ratios of carbon to nitrogen and the subsidence, thickening, and filtration characteristics of the activated sludge were obtained. It was felt, therefore, that differences in subsidence and dewatering characteristics observed would be directly related to the differences in nitrogen content. A more detailed discussion of the technical approach used is contained in a subsequent section of this report.

The waste treatment plant at Scott Paper Co., Mobile, Alabama is particularly well-suited for this investigation for several reasons:

1. There is a ready supply of nutrient deficient waste available for study.
2. Facilities are available for the introduction of controlled amounts of ammonia nitrogen and phosphorus.
3. The secondary (activated sludge) treatment facilities consist of two isolated and completely independent plants, which is ideally suited for the type of controlled study that is required.
4. The primary treatment facilities at Scott Paper Co. consist of a single, large primary tank, and therefore, each of the two separate secondary plants is fed primary effluent of identical quality.

It was proposed that the objectives of this research project be achieved through the performance of a work scope comprised of the following phases: (1) literature search, pilot plant dewatering equipment construction and project planning, (2) pilot plant installation and start-up, (3) system operation and evaluation, and (4) final report and site restoration. The following description of the project phases and work tasks is intended to outline the scope of work performed for the project.

Phase I - Preliminary Project Planning

1. Literature Search

A review of published literature and plant operating data was made to supplement existing knowledge about activated sludge treatment of nitrogen deficient wastes. Although investigation has shown that the available data is based essentially on bench-scale laboratory studies, an awareness of what has been observed in this manner was useful in the design of test plans and analytical techniques for the full-scale investigation.

2. Pilot Dewatering Equipment Construction

The effects of carbon to nitrogen ratio on the thickening and filtration characteristics of the activated sludge from the control and test plants were evaluated using pilot flotation thickening and vacuum filtration equipment. This work task was associated with the design, fabrication, assembly, and shipment of the pilot equipment to the test site.

3. Site Preparation

Certain site preparations and modifications were required at the test site to accept and house the pilot thickener and filter and appurtenant equipment. Moreover, preparations were made with regard to waste flow access, access to utilities, and waste discharge.

4. Design of Detailed Test Plans

The objective of this task was to design in detail the test plans by which the investigation was to be governed. Such plans included operational and sampling procedures, analytical techniques and methods, and data recording and evaluation procedures. The test plans defined such elements as the type and placement of automatic sampling equipment, schedules and procedures for manual sampling, type and number of analytical determinations, type, number, and duration of operational runs, and process parameters to be investigated.

Phase II - Pilot Installation and Start-Up

After the pilot flotation thickener and vacuum filter units were built and the site had been prepared to accept them, they were installed and put through start-up procedures.

Phase III - System Operation and Evaluation

This phase comprised the testing and evaluation which provided the information needed to meet the project objectives.

1. Investigation Per Test Plans

This task encompassed the entire physical aspect of the testing program and was guided by the test plans designed in Phase I.

2. Evaluation of Test Data

The test data generated was evaluated as it became available and enabled operational and analytical changes to be made to the test program as required.

Phase IV - Final Report

The final portion of the project work scope consisted of preparing this final report, which is a complete documentation of the overall project, including results of the literature search, test data, evaluations, conclusions, and recommendations.

SECTION IV

LITERATURE SEARCH

The objectives of the project are to evaluate on a full-scale basis the effects of the carbon to nitrogen ratio on the subsidence, thickening, and dewatering characteristics of activated sludge. The purpose of the literature search was to gather and accumulate available pertinent and relevant information, such as, all factors, variables, parameters, experimental and reference data which would aid in the conduct of the investigation and in achieving the project objectives. For example, a review of the published literature was expected to supplement existing knowledge about activated sludge treatment of nitrogen deficient wastes and to be useful in defining the problems in the design of the test plans, operating procedures, and analytical techniques for the full-scale investigation. At the outset, it was determined that the following broad areas were pertinent:

1. The need for research in sludge handling and disposal.
2. Activated sludge, the area in which research would yield the greatest benefits.
3. The role of nitrogen in the activated sludge process.
4. The effect of nitrogen on the settling, compaction, and dewatering properties of activated sludge.

The documentation of the literature search portion of the project is presented below and will follow the order outlined above. References to the literature in the ensuing discussion may be found in the References section of this report.

The Need for Research in Sludge Handling and Disposal

The primary purpose of waste treatment is to prevent pollution by removing solids from sewage and industrial wastes. The by-products of waste treatment, namely, treated effluent and sludge solids, must be disposed of efficiently and economically. In general, researchers and design engineers have, in the past, considered waste treatment and sludge disposal as separate entities. In fact, sludge disposal has been generally neglected in favor of the problems associated with the advanced waste treatment of conventionally treated wastewater effluents. In general, the advanced waste treatment methods result in the production of more voluminous residual sludges which are more difficult to handle and treat.

Sludge handling and disposal should be considered an integral part of the total waste treatment process. The effectiveness with which sludge handling and disposal are carried out influence the efficiency of the wastewater treatment system. For example, digester supernatants, thickener effluents, filtrates, centrates, and elutriates are returned to the clarification and biological treatment units of the wastewater treatment system. The effect of these flows on plant performance are not normally taken into account in plant design. Inefficient sludge handling, therefore, will overload these units with fine solids, thereby lowering overall treatment efficiency.

Sludge handling and disposal is a costly operation. It is estimated that it represents 25 to 50 percent of the total capital and operating cost of a wastewater treatment plant(1). In addition, the problem is growing. Within the next ten to fifteen years, the volume of sludge requiring handling and disposal is expected to increase by 60 to 70 percent(2). By far, the major portion of the increased sludge volume expected will be obtained from secondary treatment sludges, which are less concentrated than primary sludges, and which are most difficult and expensive to treat(2). For example, in 1980 it is anticipated that 140 million gallons per day of secondary sludge (2% solids) will be produced, whereas only about 10 million gallons per day of primary sludge (6% solids) are expected in that year(2).

It may be apparent from the above brief discussion that research into sludge handling has great potential value for increasing the efficiency of solids disposal, thereby increasing the process efficiency and decreasing the cost of the total waste treatment process. It may also be evident that the greatest benefit which may be derived from sludge handling research lies in the investigation of means for significantly reducing secondary treatment sludge volumes for subsequent treatment and disposal.

Activated Sludge, the Area in Which Research Would Yield the Greatest Benefits

Activated sludge is a secondary treatment plant sludge which is the most difficult sewage plant sludge to handle and dispose of and which is produced in greater quantities than other sewage plant sludges (2500 cu ft waste activated sludge per million gallons raw sewage versus about 400 cu ft primary sludge per million gallons of raw sewage)(3). The handling and disposal of sludges arising from the treatment of wastewater consists of a series of dewatering steps, and for activated sludge this series begins in the final clarifier and may proceed through thickening, digestion, elutriation, vacuum filtration, and the final ultimate disposal step. Any mechanism which will enhance the settling and compaction characteristics of activated sludge will enhance the efficiency of sludge handling and ultimate disposal.

One of the most difficult and important steps in the ultimate disposal of activated sludge is the thickening process. Increasing the ability to remove water in the thickening process will improve the subsequent steps and decrease the cost of digestion, elutriation, dewatering by filtration or by centrifugation, and disposal by drying, oxidation, land-fill, or sea disposal. In addition, the thickening process will decrease the volume of digester supernatant, filtrates or centrates, and elutriates returned to the clarification and biological treatment units of the wastewater treatment system.

The thickening process is responsible for removal of the majority of the water associated with the activated sludge despite its hydrophilic nature. For example, by increasing the solids concentration in activated sludge from an initial concentration of 0.5% to 3.5% (an incremental increase of 3.0%), 86 percent of the water associated with the original sludge is removed.

The Role of Nitrogen in the Activated Sludge Process

The objective of biological treatment of organic wastes by activated sludge is the removal of the carbon present in the organic matter. The organic carbon is biologically removed from the wastewater flow by means of two mechanisms, namely, by oxidation and by synthesis, and these processes proceed simultaneously. The organic carbon removed by oxidation is converted to carbon dioxide and is lost from the system. The oxidation reaction does not require a nitrogen source. The organic carbon removed by bacterial synthesis is converted to cell protoplasm, and this process requires a nitrogen source. The organic carbon removed by bacterial synthesis is not generally removed from the system and has to be dealt with further. In fact, the major portion of the residual sludges from activated sludge systems, which require ultimate disposal, contain the products of cell synthesis.

The proportions of organic carbon which take part in the oxidation and synthesis reactions will vary with the nature of the organic matter in the wastewater. This has been demonstrated for pure organic compounds in bench scale investigations(4)(5). It is evident that the oxidation-synthesis relationship becomes more complicated where the wastewater contains a combination of biodegradable organic compounds. Domestic sewage is a case in point, and the oxidation-synthesis relationship has been estimated for representative sewages(5). The situation becomes more complex in the case of industrial wastes, which are not similar to domestic sewage in composition, where the relative amounts and types of organic compounds may vary widely.

Nutrients, such as nitrogen and phosphorus, are essential for biological protoplasm and growth in the synthesis reaction, and the necessary nutrients must be present in the proper amounts for optimum stabilization of the wastewater. It is apparent from the previous discussion concerning the oxidation-synthesis relationship that the amounts of nutrients required will vary with the nature and quantity of the organic matter in the wastewater. Domestic sewages usually contain the required nutrients in excess. On the other hand, industrial wastes are generally nutrient deficient, and nutrients must be added when these wastes are biologically treated. In this regard, it is important that industrial wastes be fortified or supplemented with nutrients as economically as possible. Ideally, economics favor a high oxidation-low synthesis (low nutrient demand) system.

It has been well established (4)(6)(7)(8)(9)(10) that nitrogen enters synthesis at the oxidation level of ammonia. Other forms of inorganic nitrogen, such as, nitrites and nitrates, are available for use in synthesis reactions, but they must first be converted to ammonia before they become available. Nitrites and nitrates are converted to ammonia by intermediate conversion reactions designated as assimilatory reductions (4)(6)(9).

Although all forms of inorganic chemical nitrogen appear to be effective for nitrogen supplementation(4), it is indicated that the rates of oxidation and the nutrient requirements will also vary with the form of nitrogen nutrient used (6)(13). For example, an investigation (13) was recently conducted to determine the form of nitrogen to add to a nutrient deficient wastewater to achieve maximum stabilization in the minimum time. Rates of oxidation using ammonium sulfate, ammonium nitrate, ammonium chloride, potassium nitrate, sodium nitrate and urea were investigated. It was concluded that ammonium sulfate was the most effective and the most economical nitrogen supplement tried. Moreover, it is usually not advisable to add nitrites or nitrates as nitrogen supplements because they also serve as a secondary source of oxygen for the organisms. For example, in final clarifiers, where the available dissolved oxygen may be depleted, nitrites and nitrates are reduced to nitrogen gas bubbles, which attach themselves to the activated sludge solids, resulting in floating sludge.

The relative cost of commercially available nitrogen nutrient materials is shown below(16). The cost of the nutrient material increases with an increase in the magnitude of the number assigned.

Anhydrous Ammonia (c.l.)	100
30% aqueous ammonia (c.l.)	107
$(NH_4)_2SO_4$ bulk (c.l.)	170
$(NH_4)_2SO_4$ bagged (l.c.l.)	250
Anhydrous Ammonia 150 lb cylinders)	300

NOTE: c.l. = carload lots
l.c.l. = less than carload lots

Organic nitrogen in the raw waste is also a nitrogen source available to the organisms for synthesis, however, the amount of organic nitrogen that becomes available for bacterial assimilation varies widely, depending on the nature of the waste and the temperature of stabilization(14)(15).

Nitrogen requirements for biological waste treatment are usually expressed in the form of food to nitrogen ratios. The most commonly used form is the BOD: nitrogen ratio, and the magnitude of this ratio most generally used in determining nutrient nitrogen requirements is about 20:1 (6)(15)(16)(17)(18). This value is arbitrary, and it usually provides for an excess of nitrogen in all cases. Excess nitrogen is costly and may cause a pollutional load downstream of the treatment facility. In the past, the BOD to nitrogen ratio has been applied without regard to the nitrogen form used, the function of the nitrogen in the system, or the requirements of the waste, therefore, it is indicated that this ratio is inaccurate, uneconomical, and misleading(6). This emphasizes a need for a simpler method for the determination of nitrogen nutrient requirements for a given wastewater, with due consideration given to the nitrogen form to be provided.

From a plant process control standpoint, the BOD:N ratio is ineffective because of the long duration required for the BOD test (5 days). In the past, total organic carbon (TOC) has been used for measuring the pollutional level of wastewaters, but the analytical methods available were also time-consuming. However, with the recent development of carbon analyzer equipment, a rapid (10-15 minutes) and simple method is available for determining organic carbon in aqueous wastewater samples. Moreover, the TOC analysis is free from the limitations and interferences associated with the oxygen-based analyses of COD and BOD. It is not expected that TOC will replace ~~BOD~~ COD and BOD. TOC is an important parameter in this study, and TOC has the following advantages and attributes(19):

1. TOC concentration is a fundamental pollution parameter in that it provides a measure of the organic content of a wastewater.

2. The variability in the ratio of COD:TOC in a wastewater is an indication of the fluctuation of constituents in the wastewater. As a corollary to this, when there is no significant constituent fluctuation in a wastewater, COD may be correlated with TOC.

2. Because the measurement of TOC is simple and rapid when employing a carbon analyzer, monitoring of a wastewater stream for TOC is an effective plant process control for detecting changes in organic carbon concentrations.

It was pointed out previously that the synthesis reaction requires a nitrogen source in the production of bacterial protoplasm. It is indicated that true protoplasm has the formulation, $C_5H_7O_2N$, and is predominant in the sludge masses produced from high synthesis systems which have been fed with sufficient nutrients. When nitrogen is taken into the bacterial cell for synthesis, it combines with carbon, hydrogen, oxygen and sulfur to form amino acids, which are in turn linked together to form proteinaceous material. Moreover, the reaction is reversible, for when the bacterial cell dies, it lyses and releases the nitrogenous material back into solution as organically bound nitrogen. This nitrogen is available for use by other bacteria for synthesis if it can be split out of its complex molecule.

In low nitrogen-fed systems, the amount of biological growth that can be formed is limited by the nitrogen available, and most of the organic carbon which would have been utilized for protoplasm synthesis is processed through the bacterial cell and discharged as waste product. Symons and McKinney (4), in controlled bench scale tests, showed that the waste product produced, which required no nitrogen, is a material high in polysaccharides, is irreversibly formed (resists biological degradation), and interferes with sludge dewatering. The polysaccharide accumulation in nitrogen starved systems was confirmed by Gaudy (11). It was also shown by Wilkinson(12) that when the nitrogen source becomes limiting, the amount of polysaccharides produced per cell rose to a maximum level. This increase was reflected in both intracellular and extracellular polysaccharides.

As the nitrogen supplementation of a nutrient deficient waste is increased, the rate of sludge growth is increased(6)(14) and the amount of bacterial protoplasm is also increased(4) until an excess of nitrogen is applied. A qualitative measure of the protoplasm and non-protoplasm material (polysaccharides) present in a sludge is the organic nitrogen content and percentage nitrogen content. For example, in low nitrogen fed systems, the organic nitrogen (the measure of protoplasm) and the percentage nitrogen (the measure of polysaccharide build-up) contents are relatively low. As nitrogen supplementation is increased, the organic nitrogen and percentage nitrogen contents of the sludge may be expected to increase as the formation of protoplasm increases and polysaccharide content decreases. It is indicated that a percentage nitrogen (based on the volatile solids of the dried sludge) of less than 7% is indicative of a nitrogen nutrient deficiency(20).

Up to this point, no detailed mention of phosphorus as a necessary nutrient in biological oxidation has been made. Phosphorus is also essential to biological growth and must be present in the proper amounts for the effective biological stabilization of wastewaters. Again, the most common form used to express phosphorus requirements is the food to phosphorus ratio, namely, BOD:phosphorus, and the magnitude of this ratio most generally used in determining phosphorus requirements is about 100:1. A ratio of 100:1 usually provides for an excess of phosphorus in all cases. Again, excess phosphorus is costly and may cause a pollutional load downstream of the treatment facility.

Of course, sufficient phosphorus should be added to avoid a phosphorus deficiency, and a good index of phosphorus deficiency is the percentage phosphorus content of the dried activated sludge, based on volatile solids. It is indicated that a value less than 1.2% phosphorus (based on the volatile solids of the dried sludge) is indicative of a critical phosphorus deficiency(20).

The relative cost of commercially available phosphorus nutrient materials is presented below(16). The cost of the nutrient material increases with an increase in the magnitude of the number assigned.

75% phosphoric acid, bulk (c.l.)	100
75% phosphoric acid, drums (l.c.l.)	133
Monoammonian phosphate (l.c.l.)	126
Diammonian phosphate (l.c.l.)	133
Monosodium phosphate (l.c.l.)	165
Trisodium phosphate	256

NOTE: c.l. = carload lots
l.c.l. = less than carload lots

The Effect of Nitrogen on the Settling, Compaction, and Dewatering Properties of Activated Sludge

It is the nature of the activated sludge produced during treatment which determines the hydrophilic character of the sludge. There is evidence in both the literature and plant operating data that the nitrogen content of activated sludge is related to the subsidence and dewatering properties of the sludge. Symons and McKinney (4), Kraus(21), and Helmers(22), advised that several mg/l of inorganic nitrogen be present in the final effluent to assure sufficient nitrogen for metabolism in the activated sludge process.

A study by Taylor et al(23) showed that nitrogen concentrations influenced settling conditions in treating liquid industrial wastes by the activated sludge process. Increasing the nitrate-nitrogen content of the activated sludge caused the SVI to drop to one-third of its initial value and rise again, suggesting an optimum nitrate concentration. Increasing the ammonium-nitrogen content initially reduced the initial SVI value and rise again, suggesting an optimum ammonium-nitrogen concentration. It appears that nitrogen to BOD ratios were related to the settling and compaction characteristics of the activated sludge. Although the data were not presented, it is assumed that the nitrogen to carbon ratios would vary in a manner similar to the nitrogen to BOD ratios.

Hartmann(24), in a discussion on the nature of activated sludge floc, states that "... chemical and physical properties of the activated sludge floc are related to its content of organic nitrogen". He asserts that a sludge high in organic nitrogen will be characterized by a large surface area and reduced settleability. The source of data or test conditions for these conclusions, however, are not stated.

Symons and McKinney(4), in controlled bench scale tests, showed that in the absence of nitrogen the solids accumulation was greater than in the nitrogen supplied control system, and that the final product of bacterial metabolism was no longer true protoplasm but a different product, high in polysaccharides. The polysaccharide accumulation in nitrogen starved systems was confirmed by Gaudy(11). It was also shown by Wilkinson(12) that when the nitrogen source becomes limiting, the amount of polysaccharides produced per cell rose to a maximum level. This increase was reflected in both intracellular and extracellular polysaccharides.

An indication of nitrogen content influencing sludge concentration is provided by Helmers(22). In the source of his experiments aimed at identifying some properties of different types of industrial wastes, it was observed that nutritionally deficient activated sludges were more difficult to dewater by filtration, more so at higher BOD loadings than at lower loadings.

Another indication of the detrimental effect of nitrogen limiting systems on the thickenability of activated sludge was obtained from a study made(24) of the 1967 operating data from the San Jose, California Water Pollution Control Plant, which uses the activated sludge process for purification and flotation thickeners for concentrating the waste activated sludge. As a result of a study of the operating data, the following observations were made:

1. Residual ammonia in the plant effluent decreased, and at times was completely absent.
2. The sludge volume index (SVI) increased beyond the normal range (60-80).
3. Effluent quality deteriorated under increased BOD loadings, and, simultaneously, thickening of the waste activated sludge became more difficult.

Moreover, a trend was observed between the mean total nitrogen to volatile solids ratios and mean SVI's. The trend was toward higher SVI as the nitrogen level dropped.

Although it has been indicated from the above discussion that the settling, compaction, and dewatering properties of activated sludge are detrimentally affected in nitrogen limiting systems, it is interesting to note that, in these systems, an immediate or concurrent decrease in purification capacity is not obtained. In the absence of nitrogen, the activated sludge purification process will ultimately fail, however, the purification process may continue for a significant length of time before failure occurs(4). For example, in laboratory investigations, it was reported(4) that in the absence of nitrogen, the purification process continued for three to four weeks before the system failed.

The literature presents an opinion based solely on laboratory batch test procedures. Biological systems supported on synthetic substrates behave differently than do sewage-fed systems(23). The batch reactor and continuous flow-through laboratory models eliminate normal flow variability, both quantity-wise and quality-wise, that are experienced in actual sewage treatment. Valid and more practical results may be obtained by controlled testing at a prototype activated sludge purification plant.

SECTION V

EXPERIMENTAL SYSTEM INVESTIGATED

The Scott Paper Co. secondary treatment facilities in conjunction with a small scale flotation thickener and belt vacuum filter will provide the system in which the effect of carbon to nitrogen ratio on the sludge characteristics may be quantitatively evaluated with respect to subsidence, thickening, and vacuum filtration. A description of these facilities is presented below.

Scott Paper Company Waste Treatment Facilities

The Mobile, Alabama Mill of Scott Paper Company's Southern Division is located in the northeast section of the City, on the bank of Chickasaw Creek, near its confluence with the Mobile River. The production is nominally 1,365 tons per day of sulfate pulp and paper, 1,200 tons of which is bleached. Approximately 40% of the pulp is produced from a variety of hardwoods and the remainder from pine. Conversion to printing and specialty papers is made in one section of the mill complex on four machines while Scott's trademark products are manufactured in another section on four additional machines.

The combined mill wastewater flow, containing wastes common to bleached kraft pulp and paper mills, is comprised of the following major contributing waste streams:

1.--digester blow condensate
2.--screen room white water
3.--bleach plant alkaline and acid effluent
4.--chlorinated lime dregs
5.--liquor evaporator condensate
6.--green liquor dregs
7.--paper machine white water
8.--bark boiler ash
9.--wood waste
10.--process spills and leakage
11.--fine sand from several sources
12.--miscellaneous cooling water

A schematic diagram of the waste treatment facilities at the Mobile Mill is shown in Figure 1. The wastewater to be treated is transported to the treatment plant by means of the three sewers shown in Figure 1. A typical influent to the plant would have the following characteristics:

Flow: 49 MGD

pH: 7.1 - 8.7

Temperature: 86° - 112° F

Suspended Solids: 143 thousand lbs/day

BOD: 64 thousand lbs/day

The detention time through the plant at the above flow is about nine hours, and a typical effluent from the treatment plant consists of:

Flow: 49 MGD

pH: 7.1 - 8.7

Temperature: 84° - 108° F

Suspended Solids: 25 thousand lbs/day

BOD: 6 - 7 thousand lbs/day

The treatment plant effluent is then combined with the flow from the acid bleach sewer (see Figure 1) to produce a stream to

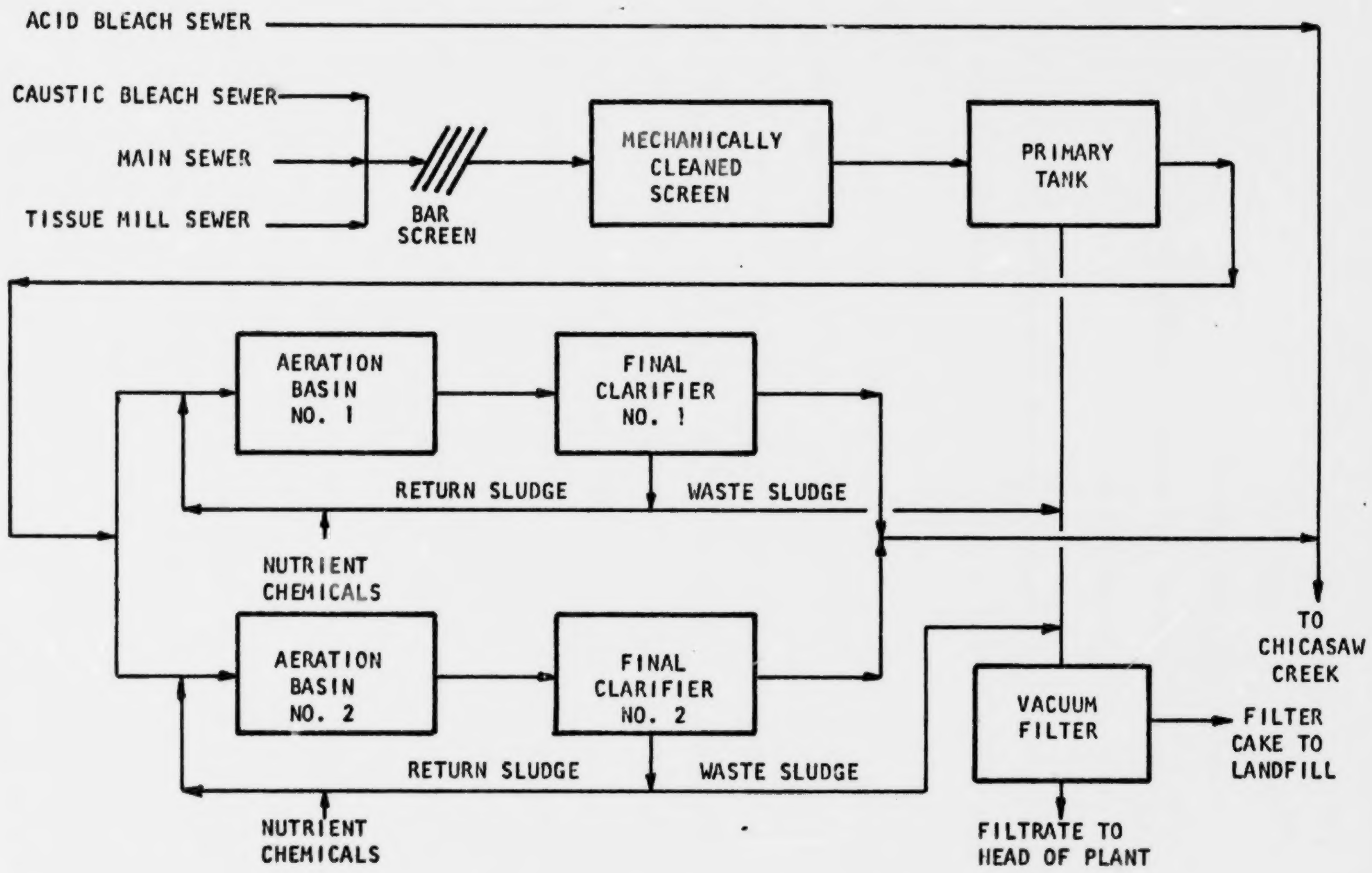

ACID BLEACH SEWER
CAUSTIC BLEACH SEWER
MAIN SEWER
TISSUE MILL SEWER
BAR SCREEN
MECHANICALLY CLEANED SCREEN
PRIMARY TANK
AERATION BASIN NO. 1
FINAL CLARIFIER NO. 1
RETURN SLUDGE
WASTE SLUDGE
NUTRIENT CHEMICALS
AERATION BASIN NO. 2
FINAL CLARIFIER NO. 2
RETURN SLUDGE
WASTE SLUDGE
NUTRIENT CHEMICALS
TO CHICASAW CREEK
VACUUM FILTER
FILTER CAKE TO LANDFILL
FILTRATE TO HEAD OF PLANT

Figure 1. Schematic diagram of waste treatment facilities, Scott Paper Co., Mobile, Alabama

Chickasaw Creek consisting of:

Flow: 63 MGD

pH: 5.5 - 7.5

Temperature: 75° - 102° F

Suspended Solids: 28 thousand lbs/day

BOD: 11 thousand lbs/day

Referring to Figure 1, the combined influent from the three sewers shown is pretreated by screening equipment, and then flows to a center-feed primary tank. The single primary clarifier, which is 322 feet in diameter at the water surface, is a concrete-lined basin having an effective volume of 9.4 million gallons. Although the primary clarifier was initially designed to handle 70 mgd raw flow, the flow presently handled results in an effluent overflow rate of about 600 gallons per day per square foot. The nominal detention time at the present flow rate is about 4.6 hours. The operation of the primary clarifier results in the removal of approximately 85% of the incoming suspended solids and about 35% of the influent BOD. The primary settled sludge is collected in an annular sump and pumped to a vacuum belt-type filter for further dewatering. The surface area of the filter is 500 square feet, operates under a vacuum of 15 in Hg, and utilizes a mono-filament polypropylene belt. The filter cake is hauled away by a contracter to a landfill, and the filtrate obtained is returned to the treatment plant. The primary clarifier overflow, contributing about 18 thousand pounds per day suspended solids and approximately 42 thousand pounds per day of BOD, is further treated in the secondary treatment plant. The secondary treatment plant consists of two completely independent activated sludge systems, and the primary clarifier overflow is divided proportionately between the two systems. The activated sludge systems include rectangular, concrete aeration basins, circular, center-feed secondary clarifiers, recycle sludge lift stations, and nutrient chemical facilities.

The aeration basins have a nominal water depth of 15 feet, contain volumes of 3.4 (No. 1) and 4.1 (No. 2) million gallons, and have a combined design capacity of 54 mgd. The secondary clarifiers are constructed of concrete, are 174 ft. (No. 1) and 200 ft. (No. 2) in diameter at the water surface, and contain volumes of 1.8 (No. 1) and 3.2 (No. 2) million gallons.

The biological solids in the flow from the aeration tanks are transported to the respective secondary clarifiers, separated, and pumped back to the aeration basins as returned sludge. A sludge recycle pumping rate of 35 to 40% of the aeration basin primary clarifier effluent overflow is used, and measurement of this flow is provided. In the returned sludge, small amounts of 75% phosphoric acid (in the ratio of 0.6 lb. phosphorus per 100 lb. BOD removed) and 28% aqueous ammonia (in the ratio of 2.8 lb. nitrogen per 100 lb. BOD removed) are added for nutrient supplementation.

Both aeration basins, in typical operation, have a nominal residence time of 2.7 hours and an organic loading of 42 lb. BOD/day per 1,000 cu. ft., or 0.6 lb. BOD/day per pound of mixed liquor suspended solids. Aeration is provided by platform-mounted, mechanical surface aerators, eleven in one basin and thirteen in the other, having rated capacities of 615 and 765 HP, respectively. The aerators maintain slightly more than one mg/l of dissolved oxygen in the mixed liquor to the secondary clarifiers.

With regard to the secondary clarifiers, current operating conditions result in settling time of about two hours and an overflow rate of 920 gal/day/sq. ft. in the smaller clarifier (No. 1), and a detention time of 2.8 hours and an overflow rate of 870 gal/day/sq. ft. for the larger clarifier (No. 2). In both clarifiers, settled sludge is removed to their respective recycle pumping stations. Each station contains two vertical pumps driven by two-speed motors which return the settled solids through parshall flumes to the aeration basins. A relatively constant biological solids content is maintained in the activated sludge systems by pumping minor portions of excess (waste) sludge, having a solids content of about 0.8%, to the primary sludge disposal system.

The outfall structure, constructed of concrete, is comprised of three, parallel parshall flumes, two of which are normally used, gates for flow regulation, and two, automatic sampling stations.

The overall effect of the treatment process, including dilution of the bleach acid effluent, is a suspended solids removal of approximately 80% and a BOD removal of 80 to 85%.

The waste treatment process is operated continuously while the Mill is operating by a single man per shift, seven days a week. Technical control analyses and reports, made daily by laboratory personnel, require about 2½ man days per week. Non-routine sampling and testing are also conducted by technical and engineering personnel on a project basis. Routine monthly summary reports concerning Treatment Plant operation and quality criteria in the Mobile River at designated locations are reported to the Water Improvement Commission.

Pilot Plant Test Facilities

To provide a system in which the sludge characteristics may be quantitatively evaluated with respect to thickening and vacuum filtration, a pilot scale flotation thickener and rotary belt vacuum filter were integrated with the existing secondary treatment facilities at the Scott Paper Company.

The overall dimensions of the pilot flotation thickener basin was 3'-6" wide by 20'-9" long by 7'-2" high. The effective thickener area was 52.5 sq. ft. with an effective water depth of 5'-6". Equipment directly appurtenant to the flotation thickener included a pump for the pressurized flow source, air injection equipment, air solution pressure tank, pressure regulating valve, raw waste activated sludge feed pumps, and flow measuring equipment.

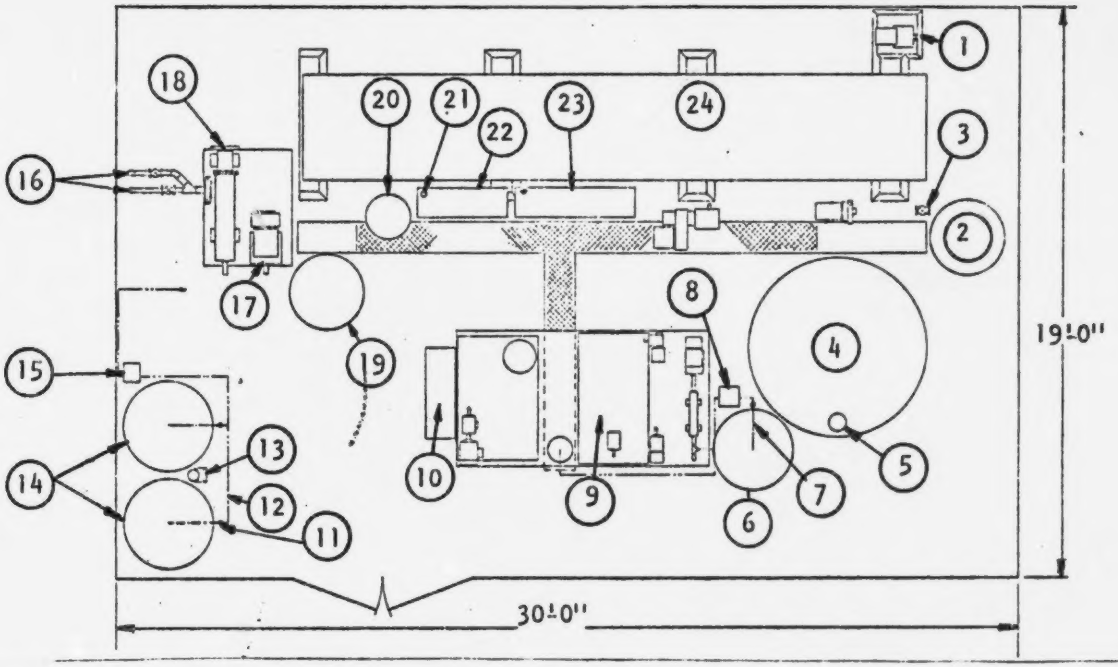
The pilot filter consisted of a rotary belt vacuum filter having a 3' ft. diameter by 1' face drum, flocculator, vacuum pump, drum drive, filtrate receiver, rotary valve, and bottom sludge feed pan.

Appurtenant to both the thickener and filter were chemical stock tanks, chemical feeders, and a thickened sludge storage tank.

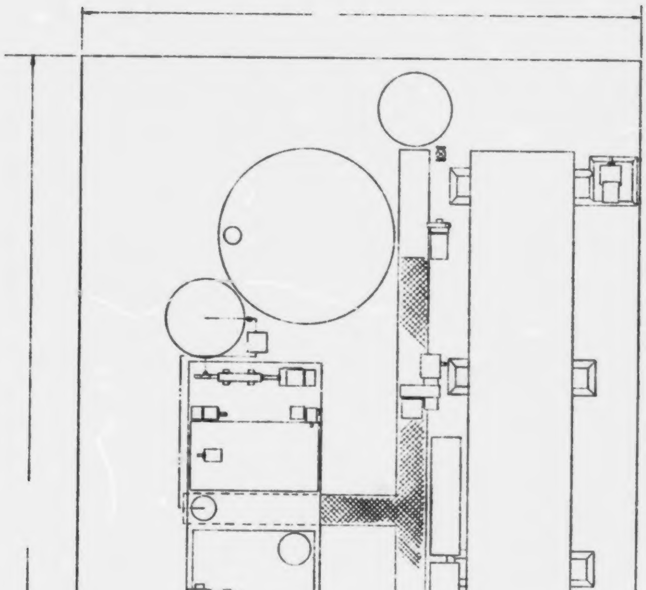
All of the above described equipment was placed on a concrete slab and housed in a suitable temporary building located in relatively close proximity to the full-scale final clarifiers of the Scott Paper Company secondary treatment plant. The arrangement of the test equipment on the concrete slab together with the overall dimensions are shown in Figure 2.

The pilot test facilities were integrated with the full-scale secondary treatment facilities by means of remote pump and pipeline connections between the secondary clarifiers and the flotation thickener.

Figure 2. ARRANGEMENT OF PILOT TEST EQUIPMENT



1. Screw Conveyor Drive - 1/2 hp
2. Alternate Position Sampling Tank
3. Remote Effluent Pump
4. Storage Tank - Thickened Sludge
5. Mixer - 3/4 hp
6. Chemical Tank
7. PVC Pipe, Fittings, Valves & Tubing
8. Chemical Feed Pump
9. Vacuum Filter Pallet
10. Vacuum Filter Electrical Control Panel
11. 1/2" Brass Ball Valve
12. PVC Pipe Fittings & Tubing
13. Mixer & Stand (1/3 hp)
14. Chemical Storage Tanks
15. Chemical Feed Pump
16. Remote Sludge Pumps 1 & 2
17. Sewage Pump Drive
18. Sewage Pump Pallet
19. Sampling Tank
20. Pressure Tank
21. Air Hook-Up
22. Pneumatic Control Panel
23. Electrical Control Panel
24. Float-Treat Separator



SECTION VI

EXPERIMENTAL PROCEDURE USED IN THE INVESTIGATION

The guidelines by which the experimental investigation was governed is set forth below and included operational and sampling procedures, analytical techniques and methods, and data recording and evaluation procedures.

System Investigated

The Scott Paper Co. secondary treatment facilities in conjunction with a small scale flotation thickener and belt vacuum filter provided the system in which the effect of carbon to nitrogen ratio on the sludge characteristics was quantitatively evaluated with respect to subsidence, thickening, and vacuum filtration. A schematic flow sheet for the system investigated is shown in Figure 3. The system studied was comprised of the following components, elements, and features:

1. Separate and independent secondary treatment "test" and "control" loops, each with its own aeration and final clarification basins.
    a. Each loop had provision for separate flow measurement and sampling of final clarifier effluent, return sludge, and waste sludge. Using these flow measurements, the primary effluent and mixed liquor flows may be calculated for each loop. Accessibility for sampling the primary effluent and aeration tank flows was also available.

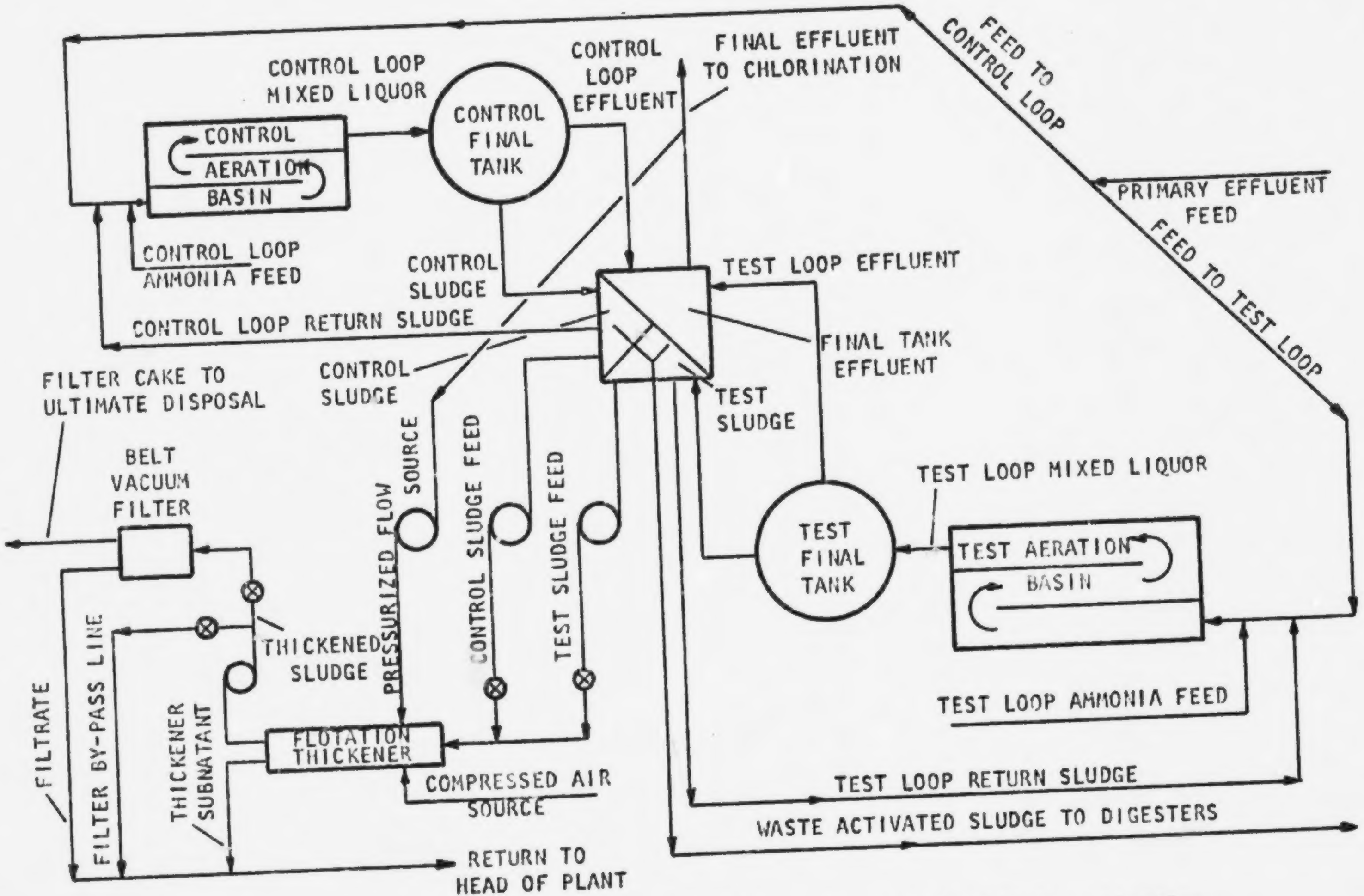

CONTROL LOOP
MIXED LIQUOR
CONTROL
AERATION
BASIN
CONTROL
FINAL
TANK
CONTROL
LOOP
EFFLUENT
FINAL EFFLUENT
TO CHLORINATION
FEED TO
CONTROL LOOP
PRIMARY EFFLUENT
FEED
FEED TO TEST LOOP
CONTROL LOOP
AMMONIA FEED
CONTROL
SLUDGE
TEST LOOP EFFLUENT
CONTROL LOOP RETURN SLUDGE
FINAL TANK
EFFLUENT
FILTER CAKE TO
ULTIMATE DISPOSAL
CONTROL
SLUDGE
TEST
SLUDGE
BELT
VACUUM
FILTER
SOURCE
PRESSURIZED FLOW
CONTROL SLUDGE FEED
TEST SLUDGE FEED
TEST LOOP MIXED LIQUOR
TEST
FINAL
TANK
TEST AERATION
BASIN
THICKENED
SLUDGE
FILTRATE
FILTER BY-PASS LINE
THICKENER
SUBNATANT
FLOTATION
THICKENER
TEST LOOP AMMONIA FEED
COMPRESSED AIR
SOURCE
TEST LOOP RETURN SLUDGE
WASTE ACTIVATED SLUDGE TO DIGESTERS
RETURN TO
HEAD OF PLANT

Figure 3. Schematic diagram of the system used for the C/N investigation, Scott Paper Co., Mobile, Alabama

b. Each loop had provision for the controlled addition of ammonia nitrogen and phosphoric acid.
c. Each loop had provision for the separate return of settled sludge to the head end of the aeration tank.

2. Primary effluent of identical quality was fed to both secondary treatment loops, and provision for sampling the primary effluent was available.

3. Piping, pumps and valving were provided to permit alternate feeding of "test" and "control" loop waste activated sludge to the pilot flotation thickener.

4. Piping, pumps, and valving were provided for furnishing final effluent as a source of pressurized flow for the flotation thickening operation.

5. Provision was made to permit selective feeding of thickened sludge to the pilot vacuum filter.

6. Provision was made for the measurement and sampling of the flows to and from the pilot thickener and vacuum filter units.

7. Provision was made for the disposal of the thickener effluent, filter feed overflow, and filtrate flows to the head of the treatment plant.

The arrangement shown in Figure 3 allowed the "test" loop to be operated with widely varying carbon to nitrogen ratios, with resultant effects on the activated sludge observed in the clarification, thickening and filtration processes. To provide bases for comparison, sludge from the "control" loop was evaluated in alternating runs through the pilot thickener and filter.

Parameters Measured

Pertinent to the evaluation of the effects produced by controlled variation of the carbon to nitrogen ratio was the measurement of the following parameters associated with the input and output streams and with the operational characteristics of the activated sludge systems (both "test" and "control" loops), flotation thickening process, and vacuum filtration operation.

1. Activated Sludge Systems (Test and Control Loops)

   a. Primary Effluent

      (1) Flow
      (2) Temperature
      (3) pH
      (4) BOD
      (5) Total organic carbon
      (6) Kjeldahl nitrogen
      (7) Ammonia added
      (8) Phosphoric acid added
      (9) Ammonia content
      (10) Carbon to nitrogen ratio

   b. Aeration Tank

      (1) Return sludge flow
      (2) Mixed liquor flow
      (3) Temperature
      (4) pH
      (5) Organic loading
      (6) Total suspended solids
      (7) Total volatile suspended solids
      (8) Solids-liquid separation rate
      (9) SVI
      (10) Aeartion detention time
      (11) Total solids of return sludge
      (12) Total volatile solids of return sludge
      (13) Total organic nitrogen of return sludge

c. Final Clarifier

    (1) Effluent flow rate
    (2) Return sludge flow rate
    (3) Waste sludge flow rate
    (4) Effluent BOD
    (5) Total organic carbon (effluent)
    (6) Effluent ammonia content
    (7) Temperature
    (8) pH
    (9) Overflow rate
    (10) Solids loading
    (11) Detention time

2. Flotation Thickener Operation

    a. Gross Solids Loading

    b. Flows and Solids Concentration

        (1) Raw sludge feed
        (2) Pressurized flow
        (3) Thickened sludge
        (4) Thickener effluent

    c. Air Injection Rate

    d. Operating Pressure

    e. Sludge Blanket Depth

    f. Solids-Liquid Separation Rate

    g. Overhead Skimmer Operation

        (1) Skimming cycle

            (a) Duration on
            (b) Duration off

        (2) Skimmer speed

i. Chemical Treatment

    (1) Chemical used
    (2) Stock solution concentration
    (3) Rate of chemical feed
    (4) Chemical dosage
    (5) Point of chemical application

3. Vacuum Filter Operation

    a. Operating Conditions

        (1) Cycle time
        (2) Vacuum
        (3) Submergence
        (4) Conditioning chemicals and dosages
        (5) Feed sludge

            (a) Solids concentration
            (b) Flow rate

        (6) Duration of filter run

    b. Process Parameters

        (1) Yield
        (2) Filter cake solids content
        (3) Solids loading
        (4) Filtrate flow and solids content
        (5) Solids recovery

Analytical determinations were intended to be made according to "Standard Methods for the Examination of Water and Waste-Water", 13th Ed., Hach Chemical Co. analytical procedures and the Backman, Inc. procedure for total organic carbon.

Operational and Experimental Procedures

The operational and experimental procedures by which the investigation was carried out is described below. The procedures will be delineated in the form of a work scope consisting of the following three work tasks:

Task 1 - Preliminary Investigation and Planning

Task 2 - Investigational Plans

Task 3 - Data Collection and Evaluation

The following discussion identifies these work tasks, details the scope of each one, and defines their interrelationship with respect to the overall effort.

Task 1 - Preliminary Investigation and Planning

This first work task involved two work items which, when successfully completed, provided the information and details required to carry out the investigational planning and data collection and evaluation work tasks. This work task was performed during the period that the flotation thickener and vacuum filter pilot units were being designed, constructed, and shipped to the Mobile, Alabama test site and during the period that the test site was being prepared to accept the pilot units. The work items comprising this work task are described as follows:

Item 1 - Monitoring of Existing Activated Sludge Systems

The purpose of this work item was to evaluate and compare the operational and performance characteristics of the two activated sludge systems to be investigated. The evaluation and comparison of the two systems was to be carried out under identical operating and process conditions. The basis for comparison and evaluation was the analysis of data obtained from the measurement of those pertinent process parameters listed previously. Statistical significance of observed and measured differences between the two systems were to be determined. Designation of the "test" and "control" systems were to be made at that time.

Moreover, this period was used to define and refine such important elements as the placement and debugging of automatic sampling equipment, preparation of schedules, procedures and frequency for manual sampling, determination of the type and number of analytical determinations to be performed, and increasing the efficiency of analytical techniques and methods (such as determining appropriate aliquot sizes, stock solution strengths, etc.). Training of technicians in system operation, sampling collection and procedures, maintenance of equipment, and in analytical techniques and methods were accomplished as a part of this task.

As a part of Task 1, Item 1, the existing ratio of organic carbon to nitrogen (C/N) currently used in operation of the treatment plant was to be determined. The current ratio of C/N was to be used as a basis for varying the magnitude of the C/N ratio in the "test" loop during the investigational period.

Item 2 - Setting Up Analytical Laboratory

Prerequisite to the accomplishment of the objectives of Task 1, Item 1 was the procurement and installation of the sampling equipment and the analytical laboratory equipment required for the measurement and determination of the pertinent process parameters. This equipment was to be procured, installed, and debugged as quickly as possible.

Task 2 - Investigational Plans

The principal independent variable in this investigation is the ratio of organic carbon to nitrogen (C/N) in the activated sludge treatment system. The pertinent response variables affected by the C/N ratio, which are of particular interest in this study, are: (1) The subsidence and compaction characteristics of the mixed liquor activated sludge solids, (2) The thickening characteristics of the waste activated sludge solids, and (3) The vacuum dewatering characteristics of the thickened sludge obtained.

Decision parameters specify the mode of operation, and for the activated sludge treatment systems to be investigated the decision parameters include: (1) The mixed liquor suspended solids to be held, (2) The organic loading to be maintained, (3) The dissolved oxygen level to be sustained, and (4) The final clarifier overflow rate to be used. The decision parameters for the activated sludge systems to be investigated should be identical in order that they do not significantly affect the response variables to be studied.

The Principal Independent Variable - C/N Ratio

As was previously described with the aid of Figure 3, the general plan for the investigation was to operate the "test" loop of the existing activated sludge facilities with widely varying C/N ratios and to observe the resultant effects on the "test" loop clarification, thickening, and filtration processes. To provide a basis for comparison, similar observations were to be made for the "control" loop at the "control" C/N ratio. (The "control" C/N ratio was to be established as a part of Task 1, Item 1).

The C/N ratio for the "test" loop was to be closely controlled by introducing controlled amounts of ammonia nitrogen. Initially, it was expected to investigate the effects of incrementally varying the "test" loop C/N ratio from 0.5 to 1.5 times the "control" loop C/N ratio. If this range of "test" C/N ratios did not significantly affect the response variables, then the investigative range of "test" C/N ratio was to be increased and the effect determined.

It is evident that the "test" C/N ratio will be periodically changed, and it should also be recognized that periodic changes in this ratio will require a significant period of time after each change for treatment system acclimatization before meaningful testing can be resumed. A discussion of the method used for determining the duration of the acclimatization period is presented below.

The subsidence, thickening, and vacuum dewatering properties of activated sludge are dependent upon the physical, chemical, and biological characteristics of the solids. The C/N ratio is expected to have a significant effect on the physical, chemical, and biological characteristics of the activated sludge solids synthesized. Therefore, it is essential that the solids remaining from the "previous" C/N ratio be, ideally, totally removed from the system and replaced by solids generated under the "new" C/N ratio in order to realistically evaluate the effect of the "new" C/N ratio on the response variables.

In an activated sludge plant, solids are removed from the system through intentional sludge wasting, through solids lost in the final effluent, and through solids decay. The determination of the time required to remove the solids remaining from a "previous" C/N ratio is not a simple matter, for after instituting a "new" C/N ratio, the solids lost from the system by wasting, in the final effluent, and by decay consist of both "old" and "new" solids and the ratio of "old" to "new" decreases with time after a change in C/N. The approach to be used in determining the time required to effect substantial removal of solids from a "previous" C/N involved the determination of (1) the mean cell residence time and (2) the number of mean cell residence times required to effect substantial removal of the "old" cells. The development of this approach follows.

The average length of time that an activated sludge particle remains in the system may be determined using the mean cell residence time, θ_c. The mean cell residence time may be determined by taking the inverse of the cell continuity equation. The cell continuity equation can be expressed as follows (25):

$$1/\theta_c = Yq_{COD} - k_d \qquad (1)$$

where θ_c = mean cell residence time, days

Y = lb cells formed/lb substrate removed

q_{COD} = substrate removal rate, lb COD removed/day/lb VSS

k_d = lb cells lost by decay/day/lb cells in system

Equation 1 is a material balance statement for cell material or sludge solids. It states that the net growth rate, $1/\theta_c$, is a function of the rate of sludge synthesis, Yq_{COD}, minus the rate of sludge loss by decay processes, k_d. Stated another way, Equation (1) shows that if the mass of sludge solids in the system is constant, then the net growth rate (sludge production), $Yq_{COD} - k_d$, is just balanced by the solids lost from the system through sludge wasting and effluent solids loss. (In practice, many plant operators waste excess sludge at a rate that results in a constant mixed liquor solids content. This assures that the mass of sludge solids in the system is constant, all other things being equal).

Determination of the mean cell residence time from Equation (1) is difficult because the magnitude of the variables on the right hand side of the equation (1) are not readily available. However, a reasonable approximation of the mean cell residence time may be obtained readily from available operational data using the following relationship (25):

$$\theta_c = \frac{VC}{QC_1 + Q_2C_2} \quad \text{.....................(2)}$$

where: θ_c = mean cell residence time, days
V = aeration tank volume, gal
C = mixed liquor suspended solids content, mg/l
Q = effluent flow rate, gal/day
C_1 = effluent suspended solids content, mg/l
Q_2 = waste sludge flow rate, gal/day
C_2 = waste sludge suspended solids content, mg/l

Using available operational data from Scott Paper Co., Mobile, Alabama, and Equation (2), the mean residence time for the test system is:

$$\theta_c = \frac{3.4 \text{ mg} \times 1350 \text{ mg/l} + 0.18 \text{ mg} \times 7100 \text{ mg/l}}{24 \text{ mgd} \times 75 \text{ mg/l} + 0.08 \text{ mgd} \times 7100 \text{ mg/l}}$$

$$\theta_c = \frac{5868}{2368}$$

$$\theta_c = 2.5 \text{ days}$$

As pointed out previously, after instituting a "new" C/N ratio, the solids lost from the system by wasting and in the effluent consist of both "old" and "new" solids and the problem remaining is to determine the number of cell residence times required to replace all the "old" cells with "new" cells. The approach utilized to determine the required number of cell residence times was to employ the equation for the hydraulic washout of a completely mixed activated sludge system (26).

$$C = C_o + (C_f - C_o)\left(1 - e^{-\frac{t}{t_o}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where: C = concentration of "old" cells at time "t"
C_o = initial concentration of "old" cells
C_f = final concentration of "old" cells
t = time
t_o = mean cell residence time

Equation (3) is hydraulically based and does not reflect the effect of sludge growth and sludge decay, but will provide a reasonable approximation for the situation at hand. Using Equation (3) and setting $C_f = 0$,

$$C = C_o\, e^{-\frac{t}{t_o}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and, $$\frac{C}{C_o} = e^{-\frac{t}{t_o}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The number of cell residence times required to remove the "old" cells may be estimated from Equation (5), which is a semi-log equation. A plot of Equation (5) is shown in Figure 4. From Figure 4 it may be seen that about five cell residence times are required to remove the substantial portion of the "old" cells from the system.

The significance of the above discussion is that after each process change of the C/N ratio, at least five cell residence times (12.5 days days or about two weeks) will be necessary for sufficient system turnover to permit resumption of testing. It appears that the acclimitization period required is relatively short and would allow us to complete

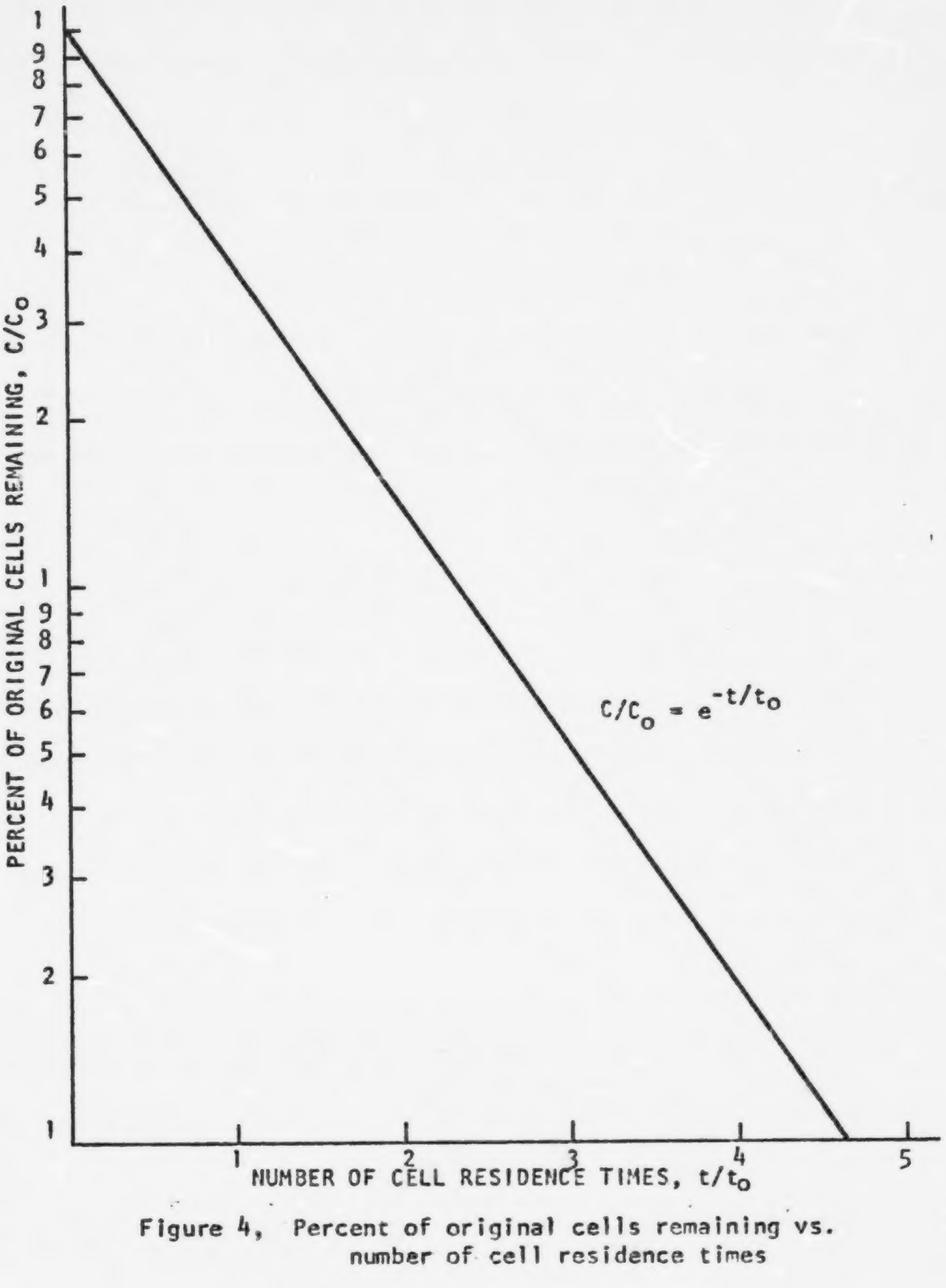


Figure 4, Percent of original cells remaining vs. number of cell residence times the desired investigation for this project. Of course, during the course of the field investigation, Equations (2) and (3) were reevaluated after each change in C/N to reflect the conditions existing at the time of the change.

The Response Variables - Solids Subsidence, Thickening and Vacuum Dewatering Characteristics

The purpose of this investigation was to determine the effect of the principal variable, C/N, on the subsidence, thickening and vacuum dewatering properties of activated sludge. Described below are means and tests to be performed which were designed to yield quantitative information regarding the response variables.

Solids Subsidence Characteristics

The primary test for determining the solids subsidence characteristics of the activated sludge mixed liquor suspensions will be the laboratory settling tests. Mixed liquor suspensions typically form a solids-liquid interface, and the subsidence of this interface with time was used as a basis for determining the solids settling rate.

Thickening Characteristics

The thickening characteristics of the waste sludges from the Scott Paper Co. activated sludge treatment systems will be obtained and evaluated in conjunction with a pilot flotation thickener (effective dimensions: 3.5 ft wide x 15 ft long x 7 ft deep). The thickener will be used to alternately thicken waste sludge from the "test" and "control" activated sludge loops.

The thickening characteristics of the waste sludges by flotation will be evaluated primarily with the aid of the parameters: solids loading, thickened sludge solids concentration, and solids recovery.

Solids loading is the principal operating independent variable and is a measure of the load or burden placed on the thickener. Solids loading is expressed as the weight of dry solids removed per unit thickener area per unit time, usually, pounds dry solids per square foot per day. In general, it may be expected that the use of higher solids loadings will result in lower thickened sludge concentrations, all other things being equal.

The main operating response variables are thickened sludge solids concentration and solids recovery, and these are variables by which the performance of the thickener is measured. It is desirable to maximize both of these performance characteristics.

The decision parameters describing the thickening mode of operation include operating pressure, air injection rate, pressurized flow rate, skimming operation variables, blanket depth, chemical used, and chemical dosage.

A secondary variable which may be used to measure the thickening characteristics is SVI. The SVI is a measure of the compactibility of the sludge and may be calculated from the results obtained from the previously discussed laboratory settling test.

Another variable of relatively minor importance is the initial rise rate of the floating sludge solids. The rise rate may be used to determine gross differences in solids-liquid separating properties of sludges and to aid in the selection of an adequate pressurized flow rate.

Cationic polyelectrolytes are generally effective as flotation aids in the flotation thickening process. In general, these polymers effectively increase the solids-liquid separation rate, permit higher allowable solids loadings and increase the clarity of the effluent over that obtained without the use of chemical aids. The effect of polymers on the separation and thickening properties of the waste activated sludges from the treatment systems investigated were determined.

Vacuum Filtration Dewatering Characteristics

The vacuum dewatering characteristics of the waste sludges from the Scott Paper Co. activated sludge treatment systems were obtained and evaluated in conjunction with a pilot vacuum filter (effective dimensions: 3 ft diameter by 1 ft face). The filter was used to alternately filter flotation thickened sludge, originally deriving from the "test" and "control" activated sludge loops.

The principal operating independent variables in vacuum filtration for a given filter medium include cycle time, vacuum level, conditioning chemical dosage and submergence.

The main response variables are filter yield, filter cake solids, filtrate suspended solids, and solids recovery. These variables are used to measure the performance of the filter. It is desirable to maximize the filter yield, filter cake solids, and solids recovery. On the other hand, it is advantageous to minimize the magnitude of the filtrate suspended solids obtained.

Bench scale tests were available as aids for selecting the magnitude of the various independent variables to be used in the pilot filter operation. For example, a Buchner funnel test was available for determination of the chemical conditioning requirements. A filter leaf test was also available to aid in selecting the sludge pick-up and drying times.

Task 3 - Data Collection and Evaluation

The purpose of this investigation was to determine the effect of C/N ratio on the subsidence, thickening, and vacuum dewatering characteristics of activated sludge. Previous sub-sections of this section delineated the plan of action for generating the necessary data to permit an evaluation which will result in achieving the purpose of the investigation. Data sheets were designed and prepared which permitted the orderly and organized recording of the information required for evaluation. Briefly, data sheets were designed for the "test" and "control" activated sludge systems, the flotation thickening process and for the vacuum filter operation. Moreover, data sheets were prepared for recording the data obtained from various laboratory tests, namely, the laboratory settling test, the laboratory flotation sludge thickening test, chemical conditioning test for filtration, and filtration leaf test.

The pertinent variables and parameters associated with the input and output streams, and with the operational and process characteristics of the treatment systems investigated have also been listed in a previous sub-section. The magnitude of the pertinent variables and parameters were obtained (1) through stream sampling and analytical determination, (2) through observation and measurement, and (3) through calculation.

For example, samples for analysis were collected from the following streams:

1. Primary Effluent
2. Mixed Liquor
3. Final Effluent
4. Return Sludge
5. Waste Sludge
6. Thickener Effluent
7. Thickener Concentrated Sludge
8. Filter Filtrate
9. Filter Cake

The samples collected will be analyzed, where appropriate for:

1. Suspended and volatile suspended solids
2. TOC/TIC analysis
3. Ortho phosphate
4. Total and volatile total solids
5. COD
6. Kjeldahl nitrogen
7. Ammonia nitrogen

Observations and measurements were made with regard to the kind and amounts of nutrients fed and with regard to the flow rates from the following streams: primary effluent, final effluent, return sludge, waste sludge, thickener feed, thickener pressurized flow, thickener effluent, thickened sludge, filter feed, chemical conditioning feed, filter filtrate, and weight of filter cake collected. Observations and measurements were also associated with the various bench scale tests. Measurements of temperature and pH were also made at pertinent points in the treatment systems to be investigated.

Calculated data was obtained using the measurements and analytical determinations made to compute such pertinent variables and parameters as organic loading, aeration and clarifier detention times, clarifier hydraulic and solids loadings, thickener and filter solids loadings and solids recoveries, contaminant removals, and C/N ratios.

The accumulated data were analyzed for significant and pertinent trends and for validity to determine if anything went wrong with the tests performed. Moreover, the data accumulated was evaluated for the effect of C/N on the subsidence, thickening, and vacuum dewatering characteristics of activated sludge. Evaluation was made by comparing the pertinent characteristics from the "test" and "control" loops. Subsidence characteristics were evaluated using the laboratory setting rates. Thickening characteristics were evaluated utilizing the solids-loading-thickened sludge concentration relationships obtained, solids recoveries observed, and the SVI's observed from the laboratory settling tests performed. Vacuum dewatering characteristics were evaluated from the vacuum filter performances obtained, namely, the yields, cake moisture contents, filtrate solids contents, solids recoveries, and conditioning chemical dosages and usages.

SECTION VII

DISCUSSION

The operating and experimental procedures used in the conduct of the investigation were those previously discussed in the previous section as a guide. Changes and modifications of routine analytical, bench and pilot plant test procedures were initiated as the investigation proceeded where warranted by the realistic field situations encountered.

Preliminary Investigations

Preliminary work was performed to provide the necessary basis and detailed information for carrying out the project investigational plans and for carrying out the ensuing substantial data collection and evaluation work anticipated. The preliminary work performed consisted of (1) Investigation of the detailed analytical and bench scale test procedures to be used and (2) Monitoring of the extisting activated sludge systems to be investigated. This work was performed during the period that the pilot test equipment was designed, constructed, and assembled at the test site.

1. Laboratory and Experimental Test Procedures

   After setting up the project laboratory, samples were obtained from individual waste streams, which were analyzed for the test parameters to be measured to determine aliquot sizes for the range of values expected and to determine the adequacy of the analytical procedures involved. Similarly, the bench scale test procedures were examined using appropriate waste treatment samples. The following changes and modifications were made as a result of the preliminary work performed:

a. Suspended Solids

The original intent was to measure all suspended solids and volatile solids using 0.45μ membrane filters. This procedure was satisfactory for mixed liquor samples. However, with effluent samples from both the primary clarifier and final clarifiers, a small aliquot (10-20 ml) was not filterable due to blinding of the membrane. A glass fiber filter was substituted for analyses of these waste streams only.

b. Total Solids

Procedures listed in Standard Methods were used. Values for total solids are reported as ppm rather than mg/l because all aliquots were weighed instead of pipetted. This procedure was followed to be consistent for all types of samples anticipated including thickened sludge.

c. Total Organic Carbon

Procedures supplied by the equipment manufacturer were used. Excessive variation in TOC was encountered with all effluent samples. The use of a tissue grinder was not effective in eliminating the variations observed. The variations obtained were attributed to fibrous solids which normally are present in a paper mill wastewater. Variations in TOC were minimized by filtering the effluent samples through Whatman No. 40 filter paper prior to analysis. Reported values for effluent samples are essentially soluble TOC.

d. Chemical Oxygen Demand (COD)

COD was intended as a backup procedure for TOC. All effluent samples analyzed for COD were also filtered through Whatman No. 40 filter paper prior to analysis.

e. Ortho Phosphate

The Hach colorimetric procedure was utilized in determining ortho phosphate. Tests were also performed to determine the effect of the length of time between sampling and analysis. It was determined that even as short a period as two hours between sampling and analysis resulted in as much as a 40% decrease in ortho phosphate values. Based on these determinations, ortho phosphate analyses were conducted on grab samples which were analyzed immediately. Pretreatment of the samples consisted of filtration through a 0.45 μ membrane filter.

f. Ammonia

Considerable difficulty was encountered with the ammonia analysis of primary and final effluents. It was originally intended to use the Nessler method for the measurement of ammonia, however, the dark color of the wastewater prevented direct Nesslerization.

It was concluded from a detailed and thorough investigation that the distillation-titration method be used for the measurement of ammonia on all waste treatment stream flows.

g. Settling Rate and Sludge Volume Index (SVI)

Settling rate or subsidence rate was one of the major variables to be studied. The settling rates in one liter graduated cylinders did not approach the overflow rate in the final clarifiers. The mixed liquor formed large floc particles and a definite interface was not always present. For this reason, settling tests were also conducted using one liter graduated cylinders and a slow stirring mechanism, rotating at 1 rpm. The slow stirring definitely improved the settling rates. The SVI was determined according to the standard test, i.e., using the sludge volume after 30 minutes settling in an unstirred 1 liter graduated cylinder. The settling rate and SVI were conducted on fresh grab samples as it had been determined that settling rate changed with sample age.

2. Monitoring of the Existing Activated Sludge Systems

The operational and performance characteristics of the two independent activated sludge systems to be investigated were evaluated and compared by monitoring the various process elements comprising the two systems. The systems were monitored by measuring those parameters pertinent to this investigation such as, suspended solids, pH, C/N ratio, TOC, BOD, BOD, NH_3, and PO_4. Moreover, bench scale settling tests, flotation thickening tests, and sludge filtration tests were performed for comparing the two systems. Finally, in addition, pilot flotation thickening and vacuum filtration tests were performed on the sludges from the two systems for comparative purposes. The discussion below enumerates the resulted obtained from the investigation conducted.

Primary Effluent

It is recognized that the primary effluent feed and characteristics are common to both activated sludge systems investigated, however, this waste stream was monitored to determine the magnitude and variability of the variables pertinent to this study. For example, wide variability would preclude obtaining grab samples for confidently characterizing this stream. A discussion of the various parameters monitored is presented below.

Suspended Solids

Bihourly samples, over a 24 hour period, for suspended solids analysis were obtained at three different times and the results are shown in Table 1. From Table 1, it may be seen by inspection for a given occasion that the variability between samples range from significant to appreciable. Similarly, the difference in magnitude of suspended solids obtained for the different occasions investigated also varied from significant to appreciable. This is borne out statistically. For example, from Table 1, the average suspended solids for the occasions studied were 51, 57, and 83 mg/l, having standard deviations of 11, 14, and 21 mg/l, respectively.

It appeared that composite samples would be necessary to adequately characterize this stream for suspended solids content.

TOC (Total Orgainic Carbon)

Bihourly samples were taken over a 24 hour period on four different days for this important parameter, and the results obtained are presented in Table 2. By inspection, for a given day, the variation between bihourly samples is significant but not appreciable. However, it was observed that the variation between different occasions would be appreciable. For the data in Table 2, the average TOC's were 210, 119, 107, and 117 mg/l, and the corresponding standard deviations were 19, 8, 12, and 18 mg/l, respectively.

It appeared that grab samples for TOC analysis may be used in setting and periodically checking the C/N ratio for the investigational purposes of this study.

Table 1. PRIMARY CLARIFIER DIURNAL VARIATION OF SUSPENDED SOLIDS

Date	Time	Suspended solids, (using a glass fiber pad), mg/l
3/27/72	1600	79
	1800	59
	2000	59
	2200	44
	2400	50
3/28/72	0200	55
	0400	42
	0600	47
	0800	51
	1000	44
	1200	40
	1400	41

		Suspended Solids
Date	Time	Glass fiber, mg/l
4/3/72	0830	52
	1030	53
	1230	51
	1430	37
	1630	75
	1830	80
	2030	66
	2230	66
4/4/72	0030	59
	0230	38
	0430	62
	0630	46

Table 1 (continued). PRIMARY CLARIFIER DIURNAL VARIATION OF SUSPENDED SOLIDS

Date	Time	Suspended solids, (using a glass fiber pad), mg/l
5/22/72	1200	80
	1400	83
	1600	100
	1800	105
	2000	68
	2200	133
	2400	78
5/23/72	0200	53
	0400	58
	0600	70
	0800	73
	1000	80
	1200	93

Table 2. PRIMARY CLARIFIER EFFLUENT DIURNAL VARIATION OF TOC, COD, AND BOD

Date	Time	TOC mg/l
4/3/72	0830	192
	1030	194
	1230	186
	1430	190
	1630	193
	1830	226
	2030	228
	2230	218
4/4/72	0030	240
	0230	224
	0430	230
	0630	200

Date	Time	TOC mg/l	COD mg/l	BOD, mg/l	
				Total	Soluble
5/18/72	0800	121	437	149	
	1000	120	437	149	142
	1200	142	510	174	
	1400	117	390	134	
	1600	108	428		
	1800	121	417	130	
	2000	123	435		
	2200	120	413	134	
	2400	122	417		
5/19/72	0200	110	398	154	145
	0400	112	376		
	0600	114	368	139	
	0800	115	350		

Table 2 (continued) PRIMARY CLARIFIER EFFLUENT DIURNAL VARIATION OF TOC, COD, AND BOD

Date	Time	TOC, mg/l
5/22/72	1600	108
	1800	114
	2000	115
	2200	96
	2400	87
5/23/72	0200	95
	0400	101
	0600	120
	0800	106
	1000	121
	1200	120

Date	Time	TOC mg/l	COD mg/l	BOD mg/l
5/24/72	1000	119	480	143
	1200	116	462	
	1400	98	477	
	1600	109	510	
	1800	106	459	
	2000	104	430	
	2200	98	426	136
5/25/72	0300	141	419	149
	0600	139	411	142
	0900	145	415	143

COD and BOD

Bihourly samples for COD analysis over 24 hour periods were obtained on two different days, and the results obtained appear in Table 2. It may be seen from Table 2 that the values of COD obtained were several orders of magnitude greater than corresponding values of TOC. Relatively low variability between bihourly samples of COD and between average values for different occasions were observed. Average COD values for the two occasions in Table 2 were 414 and 449 mg/l, and the corresponding standard deviations were 40 and 34 mg/l, respectively.

Samples for BOD analysis were also obtained on a bihourly basis and these data are also shown in Table 2. Note from Table 2 that the BOD values obtained are of the same order of magnitude as those obtained for TOC. Relatively low variability in BOD were observed between bihourly samples and between occasions.

pH

Bihourly samples for pH analysis were obtained over 24 hour periods for three different occasions. These data appear in Table 3. It may be seen from Table 3 that pH of the primary effluent varies significantly over the day, but for the most part, remains in the acceptable range, 6 to 9, for biological treatment.

Note in Table 3, 3/28/72, that an alkaline spill occurred before 10 A.M. which was apparently not equalized by the primary treatment basin.

Table 3. PRIMARY CLARIFIER EFFLUENT DIURNAL VARIATION OF pH

Date	Time	pH
3/27/72	1600	8.2
	1800	8.3
	2000	7.5
	2200	7.5
	2400	7.3
3/28/72	0200	7.2
	0400	7.2
	0600	7.3
	0800	7.5
	1000	10.0
	1200	10.1
5/18/72	0800	6.2
	1000	7.5
	1200	7.6
	1400	9.2
	1600	6.9
	1800	7.2
	2000	7.9
	2200	7.3
	2400	7.2
5/19/72	0200	7.1
	0400	6.8
	0600	7.6
	0800	7.4
5/24/72	1100	7.6
	1300	7.7
	1500	7.8
	1700	7.3
	1900	7.4
	2100	6.8
	2300	7.6
5/25/72	0100	7.4
	0500	7.8
	0900	8.6
	1200	8.1

Ammonia Nitrogen

Difficulties in the measurement of ammonia on this wastewater were previously described and discussed. Bihourly samples for ammonia analysis were obtained over 24 hourly periods for three different occasions, and these data are presented in Table 4. Note from Table 4 that two of the three sample series (3/30 and 4/3/72) were analysed using the Nessler procedure which gave erroneous results. The third sample set, 5/22/73, was analyzed using the accepted titration procedure.

Comparison of the results in Table 4 shows that the values of ammonia nitrogen obtained using the Nessler procedure were several orders of magnitude higher than those observed using the titration procedure.

It may be seen from the titration results (5/22/72) that significant amounts of ammonia are present in this industrial waste, and the source of ammonia was traced to the discharge of sanitary wastes to the treatment system.

Ortho Phosphate

Significant amounts of phosphorus were also found to be present in the primary effluent. In Table 5 are shown the significant amounts of phosphorus present in this wastewater stream.

Table 5 shows two sets of analyses. One set was analyzed for ortho phosphate immediately after sampling, and the other set shows the analysis values obtained for the same samples after several hours delay in analyzing for phosphorus. Comparison of the two data sets indicates the urgency for analyzing for ortho phosphorus immediately after sampling.

Table 4. PRIMARY CLARIFIER EFFLUENT DIURNAL VARIATION OF AMMONIA NITROGEN

Date	Time	NH_3-N, mg/l (micro-distillation plus nesslerization)
3/30/72	1430	3.83
	1730	4.03
	1930	8.28
	2130	3.95
	2330	4.00
3/31/72	0130	4.20
	0330	4.38
	0530	4.35
	0730	4.23
	1430	4.00
4/3/72	0330	6.75
	1030	7.75
	1230	5.25
	1430	5.50
	1630	5.75
	1830	5.25
	2030	4.90
	2230	5.00
4/4/72	0030	4.70
	0230	4.60
	0430	5.40
	0630	4.80

Date	Time	NH_3-N, mg/l (macro-distillation plus titration - acceptable procedure)
5/22/72	1600	1.01
	1800	1.19
	2000	0.93
	2200	0.34
	2400	0.94
5/23/72	0200	1.04
	0400	1.02
	0600	0.31
	0800	0.77
	1000	0.62
	1200	1.04

Table 5. PRIMARY CLARIFIER EFFLUENT
DIURNAL VARIATION OF ORTHOPHOSPHATE

	Time	PO_4-P, mg/l	Same sample analyzed @ 1800, mg/l
4/3/72	0930	1.4	1.2
	1130	1.9	1.2
	1330	2.1	1.1
	1530	1.8	1.0

Activated Sludge Systems

A gross comparison of the treatment efficiencies of the two independent systems was investigated using final effluent BOD as a criterion. These comparative data are shown at the top of Table 6. From Table 6, the primary effluent BOD is fairly uniform. Comparison of the final effluents from the two systems indicate that the performance of the two systems is comparable. Discrepancies in final effluent quality, such as on 4/13/72, 4/14/72, and 4/28/72 are attributed to final clarifier operation (excessive solids in the effluent).

Shown at the bottom of Table 6 are the comparative final effluent TOC data for the two systems. It may be noted from previous discussions, that samples for TOC were filtered prior to analysis and the values shown in Table 6 are essentially soluble TOC, which eliminates the effect of effluent solids on the comparison of the two systems. A comparison of the final effluent TOC data in Table 6 indicates clearly that the performance of the two systems are comparable.

In Table 7 are presented the C/N ratios for the two systems for a short period in May 1972. Previous C/N data was not calculated or measured because of the difficulties involved in measuring ammonia. The data shown were obtained after the resolution of those difficulties. Note that the ratios for the systems may be be controlled relatively closely. In Table 7, on 5/2/72, the ammonia feed pump on System #1 was down for repairs.

Table 6. BIOLOGICAL TREATMENT CHARACTERISTICS OF THE TWO ACTIVATED SLUDGE SYSTEMS

Date	Primary effluent BOD, mg/l	Final eflfuent BOD, mg/l	
		System #1	System #2
4/13/72	170	45	16
4/14/72	142	41	22
4/20/72	163	20	20
4/21/72	178	32	21
4/27/72	162	25	20
4/28/72	158	19	67

Date	Primary effluent TOC, mg/l	Final effluent TOC, mg/l	
		System #1	System #2
4/13/72	238	120	119
4/14/72	95	110	109
4/20/72	136	79	77
4/21/72	109	92	51
4/24/72	170	102	98
4/25/72	112	62	61
4/26/72	131	87	83
4/27/72	170	99	92
4/28/72	183	85	142
5/1/72	172	117	103
5/2/73	168	118	108

Table 7. C/N RATIO FOR THE TWO ACTIVATED SLUDGE SYSTEMS

Date	Primary Effluent NH_3-N, mg/l	Primary Effluent TOC, mg/l	NH_3-N added, lb/day #1	NH_3-N added, lb/day #2	Total NH_3-N, lb/day #1	Total NH_3-N, lb/day #2	Total Carbon, #/day #1	Total Carbon, #/day #2	C/N #1	C/N #2
5/1	0.450	172	591	938	684	1057	35,661	45,760	52	43
5/2	0.302	168	0	665	58	750	32,254	47,287	556	63
5/3	0.160	153	475	625	507	666	30,305	38,982	60	58
5/4	0.410	163	475	625	556	729	32,286	41,530	58	57
5/5	0.105	220	475	625	685	920	44,071	61,961	64	67

Appearing in Table 8 are organic nitrogen to volatile suspended solids ratios (expressed as % N) for the return activated sludge solids in the two systems. This was an important ratio which was followed closely during the study. It may be recalled from the literature search section of this report that values of this ratio below 7 % indicated nitrogen nutrient deficient systems. From Table 8, it may be seen that both systems were slightly nitrogen nutrient deficient during the period investigated.

Extensive monitoring of the two systems was conducted during the period 6/19/72 to 8/31/72. The data obtained are presented in Table 9 for System #1 and in Table 10 for System #2. The parameters shown in Tables 9 and 10 include settling rates (unstirred and stirred), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), percentage organic nitrogen in the return sludge, % N (expressed as the percentage of the return sludge volatile suspended solids), the carbon to nitrogen ratio, C/N (calculated from the TOC obtained from composite primary effluent samples and from the total NH3-N at the inlet to the aeration tanks), and the sludge volume index (SVI). The C/N ratio was based upon the total daily flow to each system as recorded by flow totalizers.

Several observations may be made regarding the June-July 1972 data for Systems #1 and #2 shown in Table 9 and Table 10, respectively.

1. Note from Tables 9 and 10 the extremely low values of % N obtained during the period investigated. The average % N for System #1 was 0.98% and that for System #2 was 1.50%. These values indicate gross nutrient nitrogen

Table 8. RATIO OF ORGANIC NITROGEN TO VOLATILE SOLIDS IN THE RETURN SLUDGE FROM THE TWO SYSTEMS-1972

Date	System	Return sludge volatile solids, mg/l	Return sludge organic N, mg/l	% N
3/29	1	3910	229	5.85
	2	3225	203	6.29
4/13	2	4008	250	6.24
4/20	1	6100	367	6.02
	2	4245	370	8.72
4/21	1	6465	320	4.95
	2	6767	256	3.78
4/24	1	3429	190	5.54
	2	3794	224	5.90
4/25	1	3447	168	4.87
	2	3512	213	6.06
4/26	1	3714	217	5.84
	2	3427	256	7.47
4/27	1	3823	214	5.60
	2	3726	192	5.15
5/1	1	3288	130	3.95
	2	3907	200	5.12
5/3	1	3660	150	4.10
	2	3389	178	5.25
5/4	1	3479	122	3.50
	2	3706	186	5.01
5/5	1	3962	262	6.61
	2	3890	210	5.40

Table 9 SETTLING RATE DATA, SYSTEM NO. 1 - JUNE AND JULY, 1972

Date	Settling rate, ft/hr		MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
	Unstirred	Stirred					
6/19	3.37	8.50	--	--	--	20.2	--
6/20	6.02	8.69	930	73.1	2.07	17.8	328
6/21	7.54	8.50	710	76.0	0.64	18.0	549
6/22	3.68	3.54	--	--	--	19.6	--
6/23	3.54	8.50	--	--	--	--	--
6/26	1.09	5.44	1040	80.8	--	--	567
6/27	--	--	905	83.4	0.36	26.0	--
6/29	2.00	6.60	--	--	1.08	21.5	--
6/30	1.06	18.90	875	90.0	0.79	39.7	1085
7/10	0.41	4.91	1140	89.9	1.55	37.1	816
7/11	0.99	8.25	1265	94.0	0.61	39.0	569
7/12	0.19	6.94	1180	84.0	1.17	24.5	754
7/13	0.12	7.38	1300	85.0	--	21.2	765
7/14	0.33	5.22	1125	86.2	0.49	23.4	840
7/17	0.97	3.54	1070	88.8	0.73	23.7	804
7/18	1.57	6.14	1055	91.0	1.08	23.7	844
7/19	0.35	14.16	830	81.0	1.28	24.0	1145
7/20	0.26	--	895	76.0	--	23.5	1050
7/21	2.03	11.56	915	92.3	0.80	27.8	678
7/24	1.20	12.70	1010	93.0	1.35	24.3	708
7/25	1.53	8.50	1140	95.0	--	39.0	561
7/26	4.39	5.96	935	95.7	--	29.8	588
7/27	1.95	9.10	870	85.0	0.73	21.9	678
7/28	2.06	9.12	810	86.4	--	23.5	679
7/31	2.09	9.13	1050	91.4	--	21.0	495

Table 9 (continued). SETTLING RATE DATA, SYSTEM NO. 1 - AUGUST SUMMARY

Date	Settling rate, ft/hr		MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
	Unstirred	Stirred					
8/1	5.35	18.70	940	79.7	--	43.4	511
8/2	2.50	7.40	1205	82.5	--	38.3	448
8/3	2.05	9.50	1180	82.2	--	22.6	517
8/4	1.08	6.87	1265	83.4	--	22.0	671
8/7	3.20	--	955	88.5	--	25.7	618
8/8	2.12	18.40	905	86.9	--	28.5	675
8/9	3.36	10.30	965	90.2	--	25.5	565
8/10	4.80	9.06	1180	90.0	--	26.9	466
8/11	3.30	7.08	975	--	--	17.1	549
8/14	--	--	--	--	--	21.5	--
8/15	3.03	--	840	90.0	--	20.0	583
8/16	3.04	8.94	1150	89.6	--	--	670
8/17	3.95	8.06	1000	77.0	--	--	595
8/18	3.11	8.65	885	89.0	--	32.5	678
8/21	2.71	7.55	1145	84.0	--	36.0	524
8/22	--	--	--	--	--	--	--
8/23	3.11	8.02	1025	86.0	--	29.3	507
8/24	0.71	--	996	86.4	--	31.4	808
8/25	--	--	--	--	--	--	--
8/28	2.79	13.55	905	--	2.05	--	574
8/29	3.92	6.78	--	--	2.23	34.1	--
8/30	2.83	8.60	895	96.0	2.82	36.2	637

Table 10. SETTLING RATE DATA, SYSTEM NO. 2 - JUNE AND JULY, 1972

Date	Settling rate, ft/hr		MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
	Unstirred	Stirred					
6/19	3.78	4.03	--	--	--	32.8	--
6/20	4.11	7.43	675	74.1	1.36	25.3	592
6/21	4.85	8.50	1050	87.6	--	54.8	467
6/22	3.64	6.50	--	--	--	41.9	--
6/23	5.66	10.10	--	--	--	--	--
6/26	3.25	15.20	990	79.8	3.08	--	293
6/27	--	--	810	87.5	--	32.4	--
6/29	2.32	20.50	--	--	2.27	38.8	--
6/30	4.86	17.00	975	85.0	1.56	43.2	410
7/10	4.25	5.92	1180	88.6	0.83	43.8	568
7/11	1.18	8.85	1240	89.0	0.34	40.0	637
7/12	0.59	7.39	1150	77.0	1.52	27.2	705
7/13	1.91	6.57	1160	88.0	--	26.7	500
7/14	3.96	9.67	1050	88.2	1.41	28.5	486
7/17	2.83	7.31	730	94.0	0.95	31.9	590
7/18	6.60	8.63	715	89.5	1.33	32.9	624
7/19	3.20	12.74	675	73.0	--	34.0	711
7/20	1.06	15.90	645	71.0	--	31.8	930
7/21	4.48	9.30	745	92.0	2.72	41.3	685
7/24	2.36	9.26	645	92.0	--	33.8	698
7/25	3.70	13.68	825	93.0	--	51.9	545
7/26	2.49	7.50	735	95.2	--	39.9	578
7/27	5.37	10.40	520	86.5	0.60	28.6	731
7/28	7.25	12.27	545	82.6	--	32.2	606
7/31	6.17	7.70	920	--	--	29.5	435

Table 10(continued). SETTLING RATE DATA, SYSTEM NO. 2 - AUGUST, 1972

Date	Settling rate, ft/hr		MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
	Unstirred	Stirred					
8/1	9.67	9.10	905	75.1	--	59.7	420
8/2	11.34	17.70	1015	80.3	--	42.9	375
8/3	9.67	12.74	955	80.1	--	25.3	366
8/4	9.10	10.60	860	81.9	--	22.2	430
8/7	15.00	--	975	84.1	--	24.8	410
8/8	5.85	11.89	1005	84.5	--	28.9	480
8/9	3.39	11.50	1060	87.7	--	32.5	500
8/10	5.00	12.56	965	--	--	26.4	539
8/11	8.02	8.96	845	--	--	16.5	473
8/14	2.96	17.34	1000	73.0	--	20.7	400
8/15	5.44	17.50	725	90.0	--	17.0	510
8/16	5.98	9.20	975	94.4	--	35.8	420
8/17	4.15	17.00	1135	83.0	--	--	348
8/18	15.57	13.22	975	92.0	--	30.4	297
8/21	7.08	8.50	1200	82.0	--	30.8	333
8/22	--	--	--	--	--	--	--
8/23	7.84	5.82	1070	87.0	--	26.0	355
8/24	8.78	10.62	990	86.4	--	29.0	354
8/25	--	--	--	--	--	--	--
8/28	9.26	9.44	955	--	2.59	--	283
8/29	8.85	9.14	--	--	1.56	30.1	--
8/30	11.80	13.70	785	92.0	1.16	33.4	344
8/31	11.80	12.50	780	69.2	--	23.7	334

deficiency. Comparing the magnitudes of the % N obtained during June-July 1972 (Tables 9 and 10) with those obtained during early May, 1972 (Table 8) shows the marked degree of nitrogen nutrient deficiency deterioration that took place between the two monitoring periods.

2. The above item indicates that the solids settling rate and SVI characteristics obtained from settling tests should be relatively poor and the data in Tables 8 and 9 confirm this. The average settling rate for System #1 was 2.03 ft/hr and that for System #2 was 3.74 ft/hr. The average SVI (System #1) was 725 and that for System #2 was 590.

   The stirred settling test data are also shown in Tables 9 and 10. A comparison of the stirred and unstirred test data shows that a marked increase in settling rate was brought about by stirring. It may be recalled that stirring was initiated because it imparted a more definite solids-liquid interface during the settling test than did the absence of stirring.

3. The C/N ratio for the two systems varied significantly from day to day. However, the average C/N for System #1 was 25.6 and that for System #2 was 35.8. During this period, June-July, 1972, no particular attempt was made to control C/N except for routine operational procedures by plant personnel. During August, 1972 an effort was made to control this ratio.

Similarly, several observations may be made regarding the August 1972 data for Systems #1 and #2 shown in Table 9 and Table 10, respectively.

1. The C/N ratio was controlled relatively closely for the two systems. The average C/N for System #1 was 28.9 and that for System #2 was 29.3.

2. The % N data showed that both systems were grossly nitrogen nutrient deficient.

3. The settling rate data, both stirred and unstirred, and the SVI data for System #2 were significantly better than those data obtained for System #1. An explanation for this observation is not readily apparent.

   Examining the data in Tables 9 and 10, there does not appear to be any correlation between settling rate, either stirred or unstirred, and the variables SVI, C/N, MCSS, or MLVSS. Sixteen linear regression analyses were tried on the August data. It was concluded that a correlation between settling rate and any of the above variables under the nitrogen nutrient deficient conditions investigated was not significant. Correlation coefficients obtained varied from 0.02 to 0.58 and two-thirds (12 of 16) of the correlation coefficients obtained were less than 0.30.

As a part of monitoring the two activated sludge systems, pilot flotation thickening tests were performed on the waste activated sludge from each system. Subsequently, pilot vacuum filtration tests were performed on the flotation thickened sludge generated. Generally, the following plan of action was used in the pilot plant testing:

1. Operation of the flotation thickener at a selected solids loading rate for thickening waste activated sludge from System #1 without the aid of chemicals. Sufficient thickened sludge was collected and accumulated to perform pilot vacumn filtration tests.

2. Operation of the pilot vacumn filter at two submergences and at various cycle times.

3. Steps 1 and 2, above, were repeated at approximately the same conditions utilizing sludge from System #2.

4. Steps 1, 2 and 3, above were repeated utiilizing chemical flotation aids in the flotation thickening step (Step 1).

Bench scale tests were performed prior to pilot plant testing to determine such operating variables as flotation recycle rates and chemical dosages, filter media to be used and sludge chemical conditioning dosages for vacuum filtration.

Flotation Thickening without Chemicals at a C/N of 30.

Waste sludge from each system was thickened alternately in the pilot flotation thickener. Bench scale tests were performed on each system sludge immediately prior to the operation of the pilot unit for determination of the operating recycle rate. Recycle rate is defined as the ratio of the volume of pressurized flow (air-changed stream) to that of the waste sludge flow to be thickened. Recycle rate is generally expressed as a percentage, and is related to the solids content of the waste sludge treated. For example, when thickening waste activated sludge derived from the treatment of municipal sewage, a recycle rate of 100 % is used for each 0.5 % solids in the waste sludge flow. In this investigation (August 1972), it was observed that a recycle rate of 200% was required for each 0.5% solids in the waste sludge flow. Comparison of the recycle rates required for this industrial sludge and municipal sludges is indicative of the difficulty involved in dewatering the nutrient nitrogen deficient industrial sludge.

The results of the pilot flotation thickening tests conducted without chemicals are presented in Tables 11 through 13. These tables contain the feed sludge characteristics for the system sludge in question, thickened sludge characteristics, and the operating conditions under which the tests were performed. Note that the data for System #1 sludge are presented in Tables 11 and 13, and those for System #2 sludge appear in Table 12. Thickener effluent suspended solids obtained in thickening sludges from the two systems was comparable.

It may be seen from Tables 11 through 13 that the results obtained from the thickening of the waste sludges from the two systems are comparable. Thickened sludge concentrations ranging from 2.37% to 2.87% were obtained at gross solids loadings varying from 8.8 to 12.8 lb dry solids per square foot per day. In comparison, when thickening municipal waste sludges at similar

Table 11. FLOTATION THICKENER OPERATION

Date: August 7, 1972

Sludge: No. 1 system waste activated sludge

Time	0800 hours
Suspended solids	3283 mg/l
Volatile suspended solids	2636 mg/l
Percent volatile suspended solids	80.3 %

Time	0800	1100	1230	1400	1530	Avg.
Total solids, mg/l	3979	3708	3998	3582	3876	3829
Total volatile solids, mg/l	3122	2883	3178	2824	3005	3002
Percent volatile suspended solids,	78.4	77.8	79.5	78.8	77.5	78.4

Scum:	Total solids (composite sample)	2.64%
	Total volatile solids	2.21%
	Percent volatile	83.80%

Operation Conditions:

Waste activated sludge flow rate	10 gpm
Pressurized stream flow rate (System No. 1 final effluent)	20 gpm
Chemical dosage	none
Recycle rate	200%
Skimming cycle at 2.3 fpm	30 min off, 4 min on
Sludge blanket depth (suspended)	9-12 in. at tank middle
Gross mass loading (total)	
based on suspended solids	7.5 lb/day/ft^2
based on total solids	8.8 lb/day/ft^2

Table 12. FLOTATION THICKENER OPERATION

Date: August 15, 1972

Sludge: No. 2 system waste activated sludge

Suspended solids (composite sample)	2420 mg/l
Volatile suspended solids	1630 mg/l
Percent volatile suspended	67%
Total solids (composite sample)	3108 mg/l
Total volatile solids	2501 mg/l
Percent volatile total solids	80.5%
Scum: Suspended solids (composite sample)	2.64%
Total solids (composite sample)	2.87%
Total volatile solids	2.49%
Percent volatile total solids	86.90%
Effluent: Suspended solids (composite sample)	120 mg/l
Operating Conditions:	
Waste activated sludge flow rate	15 gpm
Pressurized stream flow rate (recirculated effluent)	30 gpm
Chemical dosage	none
Recycle rate	200%
Skimming cycle @ 2.3 fpm	30 min off; 4 min on
Sludge blanket depth	9-12 in. at tank middle
Gross mass loading	
based on suspended solids	8.40 lb/day/ft^2
based on total solids	10.8 lb/day/ft^2

Table 13. FLOTATION THICKENER OPERATION

Date: August 21, 1973

Sludge: No. 1 system waste activated sludge

Total solids (composite sample)	3985 mg/l
Total volatile solids	3239 mg/l
Percent volatile total solids	81.0%

Scum:	Total solids (composite sample)	2.37%
	Total volatile solids	2.07%
	Percent volatile total solids	87.1%

Operating conditions:

Waste activated sludge flow rate	14 gpm
Pressurized stream flow rate (recirculated effluent)	28 gpm
Chemical dosage	none
Recycle rate	200%
Skimming cycle at 2.3 fpm	30 min off; 4 min on
Sludge blanket depth	9-12 in. at tank middle
Gross mass loading	
based on total solids	12.8 lb/day/ft^2

solids loadings, a thickened sludge ranging from 4% to 5% may be expected. The comparison indicates the difficulty involved in thickening the nitrogen nutrient deficient industrial sludge under investigation.

Flotation Thickening with Polymers at a C/N of 30

Cationic polymers have been found to be most beneficial as flotation aids in the thickening of activated sludges. Bench scale tests were performed to determine the cationic polymer to be used and its required dosage. From the screening tests performed, it was determined that Dow Purifloc C-31 was most effective for the sludge in question.

The results obtained from the flotation thickening tests performed with polymers are shown in Table 14 for System #1 sludge and in Table 15 for System #2 sludge. Again, these tables present the feed and thickened sludge characteristics and the thickener operating conditions under which the tests were performed. Thickener effluent suspended solids were comparable when thickening sludges from both systems.

System #1 sludge thickening test results are presented in Table 14, which shows that a thickened sludge concentration of 2.32% was obtained at a gross loading of 22.3 lb/(day)(sq ft) when using a polymer dosage of about 28 lb/ton dry solids. System #2 sludge thickening test results are shown in Table 15, and it may be seen that a thickened sludge concentration of 2.29% was obtained at a gross solids loading of 15.2 lb/(day)(sq ft) when using a polymer dosage of 104 lb/ton. Note that the appreciably higher polymer

Table 14. FLOTATION THICKENER OPERATION

Date: August 24, 1972

Sludge: No. 1 system waste activated sludge

Suspended solids (composite sample)	3940 mg/l
Total solids (composite sample)	4444 mg/l
Total volatile solids	3609 mg/l
Percent volatile total solids	81.2%
Scum: Total solids (composite sample)	2.32%
Total volatile solids	2.02%
Percent volatile total solids	86.8%
Effluent: Suspended solids (composite sample)	200 mg/l
Operation conditions:	
Waste activated sludge flow rate	22 gpm
Pressurized stream flow rate (recirculated effluent)	40 gpm
Chemical dosage (Dow Purifloc C-31)	27.92 lb/ton
Recycle rate	182%
Skimming cycle at 2.3 fpm	15 min off; 4 min on
Sludge blanket depth	9-12 in. at tank middle
Gross mass loading	
based on suspended solids	19.83 lb/day/ft^2
based on total solids	22.30 lb/day/ft^2

Table 15. FLOTATION THICKENER OPERATION

Date: August 29, 1972

Sludge: No. 2 system waste activated sludge	
Suspended solids (composite sample)	3010 mg/l
Total solids (grab sample)	2396 mg/l
Total volatile solids	1852 mg/l
Percent volatile total solids	77.3%
Scum: Suspended solids (composite sample)	2.18%
Total solids (composite sample)	2.29%
Total volatile solids	1.88%
Percent volatile total solids	82.0%
Effluent: Suspended solids (composite sample)	255 mg/l
Operation Conditions:	
Waste activated sludge flow rate	22 gpm
Pressurized stream flow rate (recirculated effluent)	38 gpm
Chemical dosage (Dow Purifloc C-31)	104 lb/ton
Recycle rate	173%
Skimming cycle at 2.3 fpm	15 min off; 4 min on
Sludge blanket depth	9-12 in. at tank middle
Gross mass loading	
based on suspended solids	15.2 lb/day/ft^2

dosage used with System #2 sludge did not increase the thickened sludge concentration obtained.

It may be concluded from the chemical flotation thickening tests performed that the thickening characteristics of the sludges from the two systems are similar.

Comparing the results obtained from thickening without chemicals (Tables 11-13) with those using polymer (Tables 14 and 15), it shows that higher thickened sludge concentrations were obtained without chemicals than with chemicals. This may appear misleading, and the comparison of the results observed were expected for the results obtained without chemicals were achieved at appreciably lower solids loadings. In general, the use of polymers permit the use of higher solids loadings to achieve the same results as without chemicals.

Vacuum Filtration Tests at a C/N of 30

During the pilot flotation thickening tests, sufficient volumes of thickened sludge were accumulated for conduct of the pilot vacuum filtration tests. From screening tests performed, it was determined that ferric chloride was the most effective chemical for sludge conditioning. Also, filter leaf screening tests were performed in selecting a suitable filter medium for use on the pilot filter. A napped polypropylene, 47 x 34 count, 2 x 2 twill medium was selected from these tests. Selection criteria used were filtrate quality and cake discharge characteristics, all other things being equal.

Prior to each filtration run, Buchner funnel tests were performed to determine the optimum chemical dosage required for conditioning the thickened sludge. For each sludge investigated, a series of tests were performed wherein the pilot filter was operated at two submergences, 25% and 37.5%, and at various cycle times, ranging from 3 minutes to 15 minutes, at each submergence. The submergence selected determined the ratio of the sludge pick-up time to the sludge drying time. For example, at 25% submergence, the drying time was twice the pick-up time, and at 37.5 % submergence, the drying and pick-up times were equal. At each condition investigated, several cycle times were permitted to elapse prior to sampling of the filter cake for analysis. The vacuum level used in filtering both system sludges was kept constant so as not to affect the comparison of the results.

The results obtained from filtration tests performed on sludge thickened without the use of polymers are shown in Tables 16 and 17. Table 16 presents the filtration results on System #2 sludge (8/17/72) and in Table 17 appear the data for System #1 sludge (8/22/73). Note from Tables 16 and 17 that two submergences were investigated, 25% and 37.5%, and that for each submergence, various cycle times were tried, varying from 3 to 14 minutes. It may also be noted that the cycle times tested were varied in random order. Of course, as the cycle times were varied, the sludge pick-up and drying times varied accordingly.

One of the factors used in evaluating filtration performance is filter cake solids content. From Tables 16 and 17, it may be seen

Table 16. VACUUM FILTER OPERATION

Date: August 17, 1972

Sludge: No. 2 system waste activated sludge thickened by dissolved air flotation

Concentration: Sludge 2.87% total solids
Sludge 2.67% suspended solids

Chemical 0.47 lb $FeCl_3$/gal. of solution

Flows: Sludge 2 gpm
Chemical 436 ml/min

Chemical dosage: 250 lb/ton dry solids (based on suspended solids)

Submergence, %	Cycle time, min	Pickup time, min	Dry time, min	Cake solids, %	Solids loading, lb/ft^2	Yield lb/hr/ft^2
37.5	14.0	5.25	5.25	9.66	.279	1.19
37.5	5.2	1.95	1.95	9.40	.198	2.28
37.5	4.1	1.53	1.53	8.88	.180	2.64
37.5	3.2	1.20	1.20	8.85	.149	2.80
37.5	7.7	2.89	2.89	10.40	.168	1.30
25.0	14.0	3.50	7.00	10.56	.226	0.97
25.0	9.1	2.27	4.55	8.90	.236	1.56
25.0	6.6	1.65	3.30	9.09	.178	1.62
25.0	5.2	1.30	2.60	9.25	.161	1.85
25.0	4.1	1.02	2.05	9.65	.133	1.95
25.0	3.2	0.80	1.60	---- does not discharge ----		

Table 17. VACUUM FILTER OPERATION

Date: August 22, 1972

Sludge: No. 1 system waste activated sludge thickened by dissolved air flotation

Concentration: Sludge 2.51% total solids

Chemical 0.235 lb $FeCl_3$/gal. of solution

Flows:

Sludge 2.0 gpm
Chemical 1022 ml/min

Chemical dosage: 304 lb/ton dry solids (based on total solids)

Filtrate pH: 4.4

Submergence, %	Cycle time, min	Pickup time, min	Dry Time, min	Cake solids, %	Solid loading lb/ft^2	Yield lb/hr/ft^2
37.5	14.00	5.25	5.25	10.48	.185	0.79
37.5	9.50	3.56	3.56	9.47	.142	0.90
37.5	7.00	2.62	2.62	9.88	.128	1.10
37.5	5.38	2.02	2.02	9.83	.116	1.30
37.5	4.13	1.55	1.55	9.75	.099	1.44
25.0	4.13	1.03	2.06	11.04	.084	1.22
25.0	5.38	1.34	2.68	11.36	.094	1.05
25.0	7.00	1.75	3.50	11.01	.104	0.89
25.0	9.50	2.38	4.76	11.70	.103	0.65
25.0	14.00	3.5	7.0	11.48	.123	0.53
25.0	3.00	0.75	1.5	10.11	.065	1.30

that for each system sludge tested neither sumbergence, cycle time, pick-up time, drying time, nor solids loading appreciably affected the magnitude of the filter cake solids content observed. Moreover, comparison of the filter cake solids contents in Tables 16 and 17 from the filtration of Systems #1 and #2 sludges shows no appreciable difference, which indicates that the filtration dewatering characteristics are similar.

Another factor used in evaluating filtration performance is filter yield, usually expressed as pounds dry solids per hour per square foot of filter area. The filter yield data for the two system sludges (thickened without chemicals) as a function of cycle time are presented in Figures 5 and 6 for the two submergences investigated. From Figures 5 and 6, it may be seen that the filter yields obtained for the filtration of System #2 sludge was consistently higher than those observed in the filtration of System #1 sludge. Two reasons are offerred for the marked differences observed: (1) difference in feed solids content and (2) differences in conditioning chemical dosage. A small part (say 10%) of the differences observed is attributed to the difference in feed solids content, 2.87% for System #2 sludge versus 2.51% for System #1 sludge. The rule of thumb is that filter yield varies linearly with feed solids content. The remainder of the differences observed is attributed to the difference in chemical conditioning dosage, 250 lb chemical per ton dry solids for System #2 sludge versus 304 lb chemical per ton dry solids for System #1 sludge. System #1 sludge was inadvertently overdosed (by 54 lb/ton)

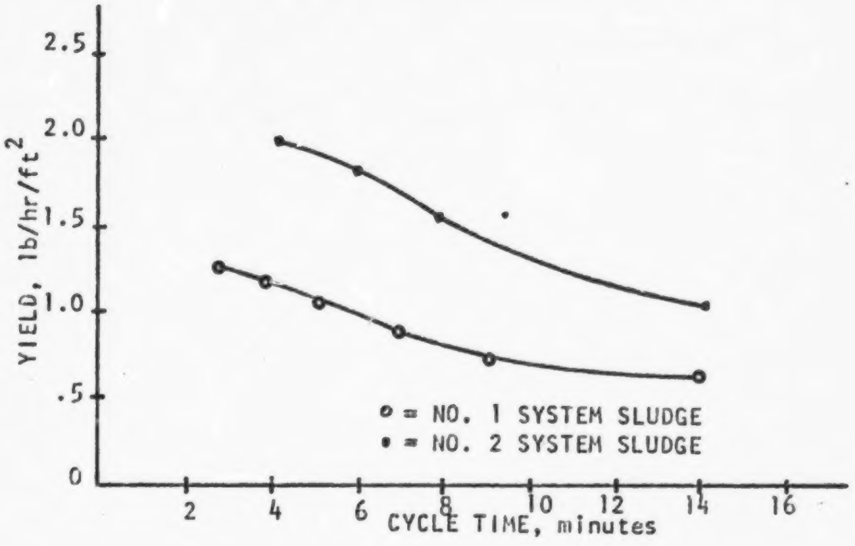


Figure 5. Yield vs. cycle time at 25% submergence

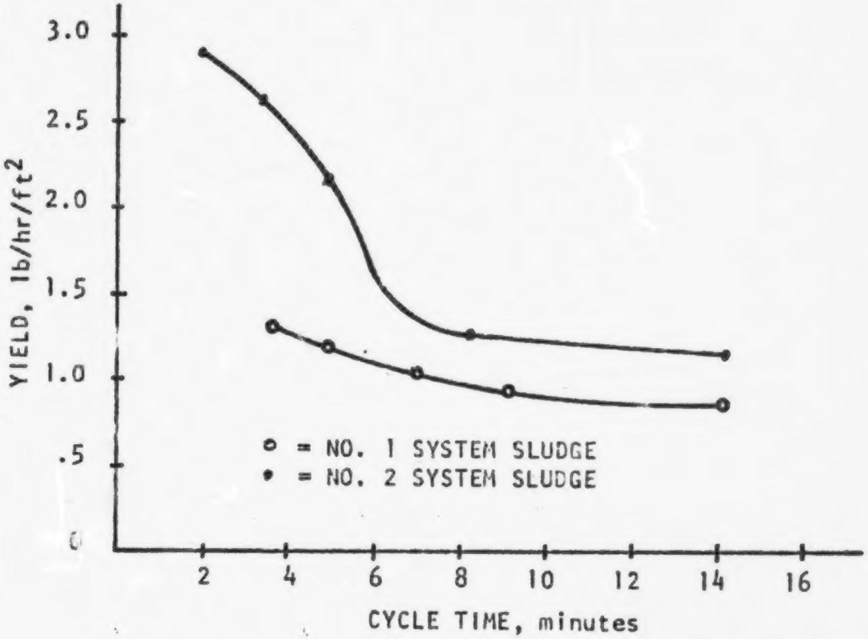


Figure 6. Yield vs. cycle time at 37.5% submergence

with conditioning chemical because of a defect in the chemical feed system. It is felt that the overdose detrimentally affected sludge pick-up, and therefore, filter yield, as may be seen by a comparison of the solids loading data in Tables 16 and 17.

The results obtained from filtration tests performed on sludge thickened with the use of polymers are presented in Tables 18 and 19 for Systems #1 and #2 sludges. Filter yields versus cycle time data for the system sludges appear in Figures 7 and 8 for the two submergences investigated. Examination of Tables 18 and 19 as well as Figures 7 and 8 indicate that the filtration dewatering characteristics of the thickened sludges from both systems are similar when based on filter cake solids content and filter yields observed.

From the above discussion of the results obtained from the monitoring of the two activated sludge systems, it is concluded that the operational and performance characteristics of the two systems are similar. Moreover, the subsidence, thickening, and filtration characteristics of the solids from both systems are also similar when the systems are operated under similar conditions.

Therefore, selection of the "test" system and "control" system was an arbitrary one. System #1, the smaller of the two systems, was designated as the "test" system in which the C/N ratio would be varied. System #2 was designated as the "control" system in which the C/N ratio would be kept relatively constant.

Evaluation of the Effect of C/N Ratio on the Subsidence, Thickening and Filtration Characteristics of the Activated Sludge Solids

Monitoring of the two systems, described above, was concluded on about August 30, 1972, Almost immediately thereafter, operational changes were made to increase

Table 18. VACUUM FILTER OPERATION

Date: August 25, 1972

Sludge: No. 1 system waste activated sludge thickened by dissolved air flotation using chemicals

Concentration:

Sludge	2.32% total solids
Chemical	0.149 lb $FeCl_3$/gal. of solution

Flows:

Sludge	2.0 gal/min
Chemical	1178 ml/min

Chemical dosage: 240 lb/ton

Filtrate dosage: 240 lb/ton

Submergence, %	Cycle time, min	Pickup time, min	Dry time, min	Cake solids, %	Solids loading, lb/ft^2	Yield, lb/hr/ft^2
37.5	14.00	5.25	5.25	9.97	.267	1.14
37.5	9.42	3.53	3.53	9.90	.226	1.44
37.5	7.30	2.74	2.74	10.41	.183	1.50
37.5	6.22	2.33	2.33	9.92	.181	1.75
37.5	5.03	1.88	1.88	10.00	.149	1.77
37.5	4.15	1.55	1.55	9.85	.138	2.00
37.5	8.38	3.14	3.14	9.83	.198	1.42
25.0	8.38	2.09	4.18	10.62	.180	1.28
25.0	14.00	3.50	7.00	11.41	.215	0.92
25.0	6.00	1.50	3.00	11.62	.149	1.49
25.0	4.00	1.00	2.00	10.78	.113	1.69
25.0	4.95	1.24	2.48	11.55	.125	1.51

Table 19. VACUUM FILTER OPERATION

Date: August 30, 1972

Sludge: No. 2 system waste activated sludge thickened by dissolved air flotation with chemicals

Concentrations:

Sludge	2.29% total solids
Chemical	0.1209 lb $FeCl_3$/gal. of solution

Flows:

Sludge	2.0 gal./min
Chemical	1121 ml/min

Chemical dosage: 188 lb/ton

Filtrate pH: 4.2

Submergence %	Cycle time, min	Pickup time, min	Dry time, min	Cake solids, %	Solids loading, lb/ft^2	Yield, lb/hr/ft^2
37.5	7.53	2.82	2.82	8.90	.185	1.47
37.5	6.33	2.37	2.37	8.27	.186	1.77
37.5	5.00	1.88	1.88	8.20	.171	2.05
25.0	14.25	3.56	7.16	9.69	.193	0.81
25.0	8.53	2.13	4.26	8.88	.181	1.28
25.0	7.62	1.90	3.80	8.64	.173	1.36
25.0	6.45	1.61	3.22	8.56	.166	1.54

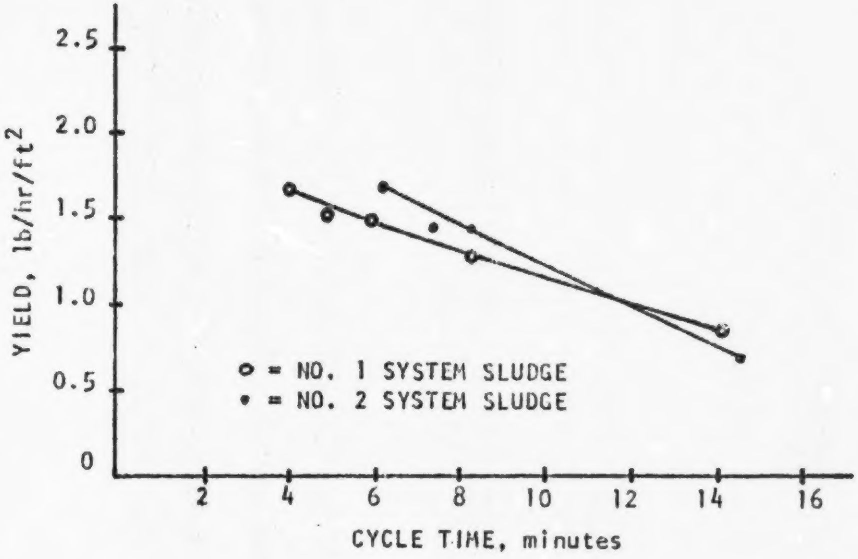


Figure 7. Yield vs. cycle time 25% submergence

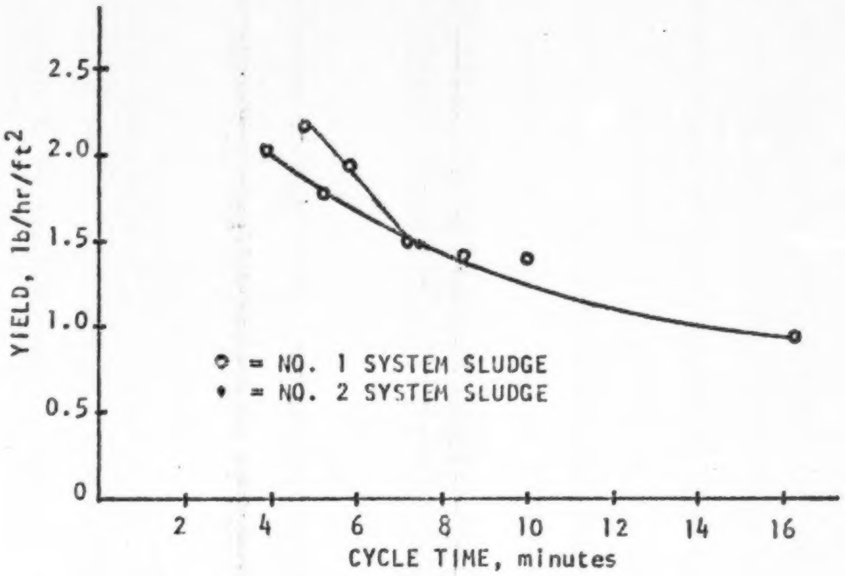


Figure 8. Yield vs. cycle time 37.5% submergence

the C/N ratio in System #1 from 30 to about 60 and to maintain the C/N ratio in System #2 at about 30. This was to be accomplished by simply decreasing the amount of ammonia addition to System #1.

In previous discussion, it was determined that the elapse of five mean cell residence times would be required to reach equilibrium after a C/N change was made. The mean cell residence time for the two systems was determined after the above described change in C/N was made, and these data appear in Table 20. From Table 20, the average mean cell residence times for Systems #1 and #2 were 2.21 days and 2.36 days, respectively. This indicated that eleven to twelve days would be required to reach equilibrium at the new C/N ratio initiated in System #1. As it turned out, because of Labor Day plant shutdown and a system upset shortly thereafter, a much longer period of time was required to achieve stabilization of both treatment systems.

Extensive monitoring of the two systems was conducted during the period 9/1/72 to 10/31/72. The data obtained are presented in Table 21 for System #1 and in Table 22 for System #2. Again, the parameters shown in Tables 21 and 22 include settling rates (unstirred and stirred), mixed liquor suspended solids (MLSS) mixed liquor volatile suspended solids (MLVSS), percentage organic nitrogen in the return sludge as previously defined (% N), the carbon to nitrogen ratio, C/N, and the sludge volume index, SVI.

Several pertinent observations may be made regarding the September-October 1972 data for System #1 (Test system) and System #2 (Control system) shown in Tables 21 and 22, respectively.

1. Both systems were still grossly nitrogen nutrient deficient as indicated by the % N data. The average % N for System #1 was about 2.0, whereas that for System #2 was about 2.4.

Table 20. MEAN CELL RESIDENCE TIME

	No. 1 System				No. 2 System			
Date	MLSS, mg/l	Solids in system, lbs	*Solids in effluent & waste activated sludge, lbs/day	Cell residence time, days	MLSS, mg/l	Solids in system, lbs	Solids in effluent & waste activated sludge, lbs/day	Cell Residence time, days
8/28/72	905	39,248	20,324	1.93	955	58,142	24,524	2.37
8/29/72	800	34,694	18,932	1.83	884	53,820	24,458	2.20
8/30/72	895	38,814	17,650	2.20	785	47,792	25,051	1.91
8/31/72	920	39,898	14,157	2.82	780	47,488	21,493	2.21
9/1/72	930	40,332	17,977	2.24	750	45,662	15,029	3.04
9/10/72	1032	44,756	11,834	3.78	608	37,016	22,799	1.62
9/11/72	752	32,613	14,412	2.26	712	43,348	19,440	2.23
9/12/72	772	33,480	19,710	1.70	856	52,115	17,501	2.98
9/13/72	688	29,837	18,619	1.60	736	44,809	20,548	2.18
9/14/72	588	25,500	12,490	2.04	532	32,389	17,496	1.85
9/15/72	828	35,909	18,214	1.97	720	43,835	13,005	3.37
			Minimum	1.60			Minimum	1.62
			Maximum	3.78			Maximum	3.04
			Average	2.21			Average	2.36

Table 21. SETTLING RATE DATA, SYSTEM No. 1 - SEPTEMBER, 1972

	Settling rate, ft/hr		MLSS,	MLVSS,			
Date	Unstirred	Stirred	mg/l	%	N, %	C/N	SVI
9/1	3.30	7.27	930	93.5	1.18	30.7	624
9/6	7.38	8.92	1055	95.7	--	38.6	512
9/7	11.89	15.90	1195	92.4	2.48	69.9	301
9/8	6.61	7.89	935	85.0	2.91	39.1	503
9/11	4.17	8.52	908	90.1	0.93	42.8	430
9/12	4.36	9.94	1030	92.2	3.21	44.1	388
9/13	4.17	11.36	885	94.4	0.93	--	429
9/14	4.87	5.68	845	92.9	1.11	--	343
9/15	8.34	9.94	890	88.2	2.51	--	393
9/18	8.34	9.23	765	90.8	3.34	--	392
9/19	11.12	12.79	770	89.6	2.25	--	351
9/20	--	--	230	77.4	--	--	348
9/21	--	--	438	87.9	2.45	--	183
9/22	24.30	49.70	820	82.9	1.30	--	195
9/25	7.64	9.23	1335	88.4	2.07	55.7	262
9/26	5.56	12.87	1240	88.3	1.88	--	258
9/27	6.95	9.94	1220	88.5	2.77	--	279
9/28	6.26	10.63	1120	88.3	--	71.3	286

Table 21 (continued). SETTLING RATE DATA, SYSTEM NO. 1
OCTOBER 1972

Date	Settling rate, ft/hr		MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
	Unstirred	Stirred					
10/2	8.34	12.78	1000	92.5	3.30	58.6	345
10/3	7.64	10.65	1080	91.2	0.45	108.5	370
10/4	9.73	12.78	1190	92.0	1.77	83.4	302
10/5	6.26	13.49	1075	85.1	--	97.5	354
10/6	6.26	13.28	1110	93.7	--	58.0	324
10/9	7.64	14.20	1040	90.3	--	69.4	327
10/10	6.60	9.94	1045	91.4	7.84	55.0	297
10/11	9.04	11.40	995	90.5	--	62.0	352
10/12	7.64	11.60	1145	86.9	1.28	61.1	306
10/13	3.96	15.10	1015	87.6	2.24	--	443
10/16	6.37	8.50	1140	88.5	1.62	70.4	333
10/17	3.54	14.87	1185	88.6	0.49	96.0	439
10/18	8.50	13.45	990	93.9	0.96	39.3	288
10/19	6.49	16.64	915	89.6	1.45	83.7	350
10/20	--	--	310	75.8	1.60	103.2	--
10/23	3.63	11.15	1155	85.7	1.15	69.4	329
10/24	7.43	11.33	1555	88.1	0.44	78.2	309
10/25	2.04	11.15	1300	88.5	1.15	46.0	454
10/26	--	--	1360	89.3	0.55	58.5	--
10/27	4.74	17.23	1345	90.7	--	41.0	327
10/30	12.74	20.90	1135	93.8	2.19	71.2	220

Table 22. SETTLING RATE DATA, SYSTEM NO. 2
SEPTEMBER, 1972

Date	Settling rate, ft/hr Unstirred	 Stirred	MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
9/1	15.22	18.00	750	94.0	0.68	27.6	333
9/6	10.20	10.90	930	90.3	--	34.5	301
9/7	6.60	10.20	1111	95.0	0.91	62.4	459
9/8	7.79	10.38	1005	83.6	2.54	35.6	417
9/11	8.34	11.36	780	87.8	1.15	35.3	385
9/12	7.65	11.36	965	89.6	1.67	39.1	321
9/13	8.34	12.07	890	82.6	2.44	--	360
9/14	6.95	12.07	955	86.9	3.02	--	346
9/15	6.53	8.52	890	86.5	3.12	--	360
9/18	6.39	9.23	1045	87.1	3.61	--	478
9/19	6.57	9.23	1030	87.9	4.23	--	417
9/20	4.86	9.23	795	86.8	3.00	--	404
9/21	4.73	7.10	870	79.9	4.70	--	391
9/22	8.34	9.94	915	87.9	2.93	--	350
9/25	5.28	11.36	930	87.1	1.47	38.0	409
9/26	6.95	8.52	975	85.1	1.48	--	338
9/27	6.95	9.23	990	85.3	1.90	--	384
9/28	7.64	8.52	930	84.9	--	44.2	355

Table 22 (continued). SETTLING RATE DATA, SYSTEM NO. 2
OCTOBER, 1972

Date	Settling rate, ft/hr Unstirred	Settling rate, ft/hr Stirred	MLSS, mg/l	MLVSS, %	N, %	C/N	SVI
10/2	6.95	9.23	835	84.4	5.60	42.5	371
10/3	13.50	10.40	850	87.6	0.39	60.1	388
10/4	9.38	10.60	995	89.4	2.62	48.3	382
10/5	6.26	9.94	945	83.6	--	55.0	434
10/6	5.56	12.80	675	94.8	--	20.4	434
10/9	9.04	12.80	895	86.6	--	57.6	402
10/10	13.20	21.30	935	93.0	8.15	44.0	385
10/11	7.00	11.40	865	86.1	--	47.0	462
10/12	8.34	6.75	965	84.4	1.47	49.0	383
10/13	7.63	14.20	1140	90.7	3.19	--	342
10/16	1.86	7.18	1610	88.8	2.93	55.0	397
10/17	1.50	5.10	1460	88.0	2.20	52.0	606
10/18	5.66	7.22	1220	91.8	1.41	32.6	311
10/19	4.39	6.23	1180	85.2	1.60	58.9	398
10/20	--	--	880	87.5	0.32	82.2	261
10/23	1.04	7.79	1230	83.7	0.67	35.3	508
10/24	1.13	9.77	1675	87.2	1.96	38.0	385
10/25	0.38	8.50	1565	88.5	0.88	29.8	537
10/26	--	--	1950	87.4	0.34	34.2	--
10/27	11.32	21.24	1850	86.8	--	28.1	232
10/31	4.11	6.20	1385	88.8	4.18	36.5	368

2. The settling rate data, both stirred and unstirred, and the SVI data for both systems were not significantly different. For example, the data for October 1972 show that the average settling rates (stirred and unstirred, respectively) for System #1 were 6.8 and 13.2 ft/hr whereas those for System #2 were 6.2 and 10.5 ft/hr. Similarly, the October 1972 data show that the average SVI for System #1 was 340 and that for System #2 was 399. Again, no apparent correlation between the settling rate data and the independent variables was observed.

3. All of September 1972 was spent in stabilizing the systems after making the C/N change in System #1. The October 1972 data show that the C/N ratios for the two systems were significantly different. The average C/N ratio for System #1 was 70.5 and that for System #2 was 45.3. The C/N ratios observed were considered significantly different, and by the middle of October 1972, the systems were considered sufficiently stabilized to perform dewatering tests utilizing the pilot flotation thickening and vacumn filtration equipment.

Waste sludge from each system was thickened alternately in the pilot flotation thickener. Bench scale tests were performed with and without chemicals at the current C/N conditions, and the results showed that a recycle rate of 200% was still satisfactory for both system sludges. Bench scale tests performed in determining polymer chemical dosages indicated that optimum polymer dosages were about 100 lb per ton of dry solids for both system sludges.

The results of the pilot flotation thickening tests performed are shown in Tables 23 through 26. These tables contain the feed sludge characteristics for each system sludge, thickened sludge characteristics, flotation effluent suspended solids, and the operating conditions under which the tests were performed. Thickening test results without chemicals are presented in Tables 23 and 24, whereas those with chemicals appear in Tables 25 and 26.

The thickening results, pertinent to this discussion, are summarized in Table 27. From Table 27, it may be seen that the thickening characteristics of the waste sludges from the two system are similar and comparable. The difference in C/N between the systems did not appear to affect the thickening characteristics of the system sludges tested. The fact that both systems were grossly nitrogen nutrient deficient is indicated to be the overriding factor for the conclusions drawn.

Again, during the pilot flotation thickening tests, sufficient volumes of thickened sludge were accumulated for conduct of pilot vacuum filtration tests. As determined from the previous filtration tests performed at a C/N ratio of 30, the same filter medium and conditioning chemical were used in the filtration tests performed in October 1972. It may be recalled that in October 1972 the C/N for System #1 was 70.5 and that for System #2 was 45.3.

Prior to each filtration run, Buchner funnel tests were performed to determine the optimum chemical conditioning dosage of ferric chloride. It was observed that the chemical conditioning dosages required in October 1972 were significantly lower than those required in the initial filtration tests conducted in August 1972. Again, for each sludge investigated, a series of tests were

Table 23. FLOTATION THICKENER OPERATION
OCTOBER 16 AND 17, 1972

No. 2 system waste activated sludge (WAS)
No. 1 system final effluent as pressurized flow

Flow rates:

waste activated sludge	15 gal./min
pressurized flow	30 gal./min
chemical flow	none

Stream	Suspended solids	Total solids
10/16 WAS composite	4,370 mg/l	5,564 mg/l
10/17 WAS composite	4,930 mg/l	--
Flotation effluent composite	915 mg/l	--
Thickened sludge 10/16	2.42 %	2.64 %
Thickened sludge 10/17	2.76 %	3.06 %

Solids Loading:

10/16	14.99 $lb/day/ft^2$
10/17	16.91 $lb/day/ft^2$
Average	15.95 $lb/day/ft^2$
Skimming cycle	3 min on; 30 min off
Blanket depth	9 to 12 in. at middle of tank

Table 24. FLOTATION THICKENER OPERATION
OCTOBER 19, 1972

No. 1 system waste activated sludge
No. 1 system final effluent as pressurized flow

Flow rates:

waste activated sludge	15 gal./min
pressurized flow	30 gal./min
chemical flow	none

Stream	Suspended solids	Total solids
WAS composite	3,515 mg/l	4,268 mg/l
Flotation effluent	112 mg/l	--
Thickened sludge 10/19	--	3.22 %
Thickened sludge 10/20	--	3.37 %

Solids loading	12.1 $lb/day/ft^2$
Skimming cycle	3 min on; 30 min off
Blanket depth	12 in. at middle of tank

Table 25. FLOTATION THICKENER OPERATION
OCTOBER 25, 1972

No. 1 system waste activated sludge
No. 1 system final effluent as pressurized flow

Flow rates:

waste activated sludge	20 gal./min
pressurized flow	43 gal./min
chemical flow	805 ml/min

Stream	Suspended solids	Total solids
WAS composite	5,820 mg/l	6,488 mg/l
Pressurized flow composite	420 mg/l	1,030 mg/l
Flotation effluent composite	250 mg/l	873 mg/l
Thickened sludge	1.97 %	2.40 %

Solids loading	26.6 lb/day/ft^2
Chemical dosage (Dow Purifloc C-31)	109 lb/ton
Skimming cycle	3 min on; 10 min off
Blanket depth	12-18 in. at middle of tank

Table 26. FLOTATION THICKENER OPERATION
OCTOBER 27, 1972

No. 2 system waste activated sludge
No. 1 system final effluent as pressurized flow

Flow rates:

waste activated sludge	20.8 gal./min
pressurized flow	42.0 gal./min
chemical flow @ 3% concentration	854 ml/min

Stream	Suspended solids	Total solids
No. 2 WAS composite	5,270 mg/l	--
Pressurized flow	270 mg/l	--
Flotation effluent	475 mg/l	--
Thickened sludge	--	2.71%

Solids loading	25.1 lb/day/ft^2
Chemical dosage (Dow Purifloc C-31)	125 lb/ton
Skimming cycle	3 min on; 10 min off
Blanket depth	12 in. at middle of tank

Table 27. SUMMARY OF PILOT FLOTATION THICKENING RESULTS OCTOBER, 1972

System #1 - C/N = 70.5
System #2 - C/N = 45.3

System	Table No.	Mass loading, lb/day/sq ft	Chemical dosage, lb/ton	Feed sludge solids concentration, mg/l		Floated sludge solids concentration, % total solids
				Susp.	Total	
No. 2	23	16.0	0	4310	5564	3.06
No. 1	24	12.1	0	3515	4268	3.37
No. 1	25	26.6	109	5820	6488	2.40
No. 2	26	25.1	125	5270	--	2.71

performed wherein the pilot filter was operated at two submergences, 25% and 37.5%, and at various cycle times (selected in random order), ranging from 3 to 12 minutes at each submergence. The vacuum level used in filtering both system sludges was kept constant so as not to affect the comparison of the results.

The results obtained from the pilot filtration tests performed on sludge thickened without the aid of polymers are shown in Tables 28 and 29 for thickened sludge from System #2 and #1, respectively. From Tables 28 and 29, it may be seen again that for each system sludge tested neither submergence, cycle time, pick-up time nor solids loading appreciably affected the magnitude of the filter cake solids content observed. Moreover, comparison of the filter cake solids contents in Tables 28 and 29 from the filtration of Systems #1 and #2 sludges shows no appreciable difference, again indicating that the filtration dewatering characteristics are similar.

The filter yield data for the two system sludges (thickened without chemicals) as a function of cycle time are presented in Figure 9 (for System #2 sludge) and in Figure 10 (for System #1 sludge) for the two submergences investigated. Examining Figures 9 and 10 shows that submergence did not significantly affect the relationship obtained. Moreover, comparison of the data in Figures 9 and 10 shows that the relationships obtained with both system sludges are not significantly different, indicating similar filtration dewatering properties.

The results obtained from filtration tests performed on sludge thickened with the use of polymers are presented in Tables 30 and 31 for Systems #1 and #2, respectively. With regard to filter cake solids contents, examination of Tables 30 and 31 shows that significantly higher cake solids contents were observed when filtering System #2 sludge at the submergences and cycle times investigated.

Table 28. VACUUM FILTER OPERATION
OCTOBER 18, 1972

Sludge: No. 2 system waste activated sludge
Sludge solids: 3.06% total solids
Chemical dosage: 151 lb $FeCl_3$/ton dry solids

Cycle time (pickup time), min	Submergence, %	Cake solids, %	Loading, lb/ft^2	Yield $lb/hr/ft^2$	
9.83	37.5	9.55	0.288	1.76	
(3.69)		10.56	0.302	1.84	
7.20	37.5	10.78	0.227	1.90	Leaf Test
(2.70)		10.94	0.271	2.26	
		9.85	0.253	2.11	
5.22	37.5	10.72	0.183	2.11	Leaf Test
(1.96)		9.84	0.221	2.54	
		10.33	0.216	2.48	
3.10	37.5	8.98	0.197	3.81	
(1.16)		10.48	0.163	3.15	
		9.18	0.177	3.42	Leaf Test
4.07	37.5	8.29	0.195	2.87	Leaf Test
(1.53)		10.09	0.192	2.83	
		10.55	0.190	2.81	
4.07	25.0	10.72	0.178	2.63	
(1.02)		10.91	0.193	2.84	
		10.57	0.184	2.71	Leaf Test
3.22	25.0	10.68	0.161	3.00	
(0.80)		10.37	0.164	3.06	
		9.19	0.178	3.32	Leaf Test
5.25	25.0	11.29	0.173	1.98	Leaf Test
(1.31)		10.85	0.219	2.50	
		10.51	0.219	2.50	
7.75	25.0	11.43	0.264	2.05	
(1.94)		10.40	0.250	1.94	
		11.71	0.201	1.56	Leaf Test
9.63	25.0	10.88	0.275	1.72	
(2.41)		11.38	0.272	1.70	

Table 29. VACUUM FILTER OPERATION
OCTOBER 20, 1972

Sludge: No. 1 system waste activated sludge
Sludge solids: 3.37% total solids
Chemical dosage: 130 lb $FeCl_3$/ton dry solids

Cycle time (pickup time), min	Submergence, %	Cake solids, %	Loading, lb/ft^2	Yield, $lb/hr/ft^2$	
11.35	37.5	10.46	0.310	1.64	
(4.26)		10.34	0.312	1.65	
9.27	37.5	10.39	0.290	1.88	
(3.48)		9.96	0.292	1.89	
7.38	37.5	9.94	0.265	2.16	
(2.77)		9.28	0.278	2.26	
5.30	37.5	9.23	0.190	2.15	Leaf Test
(1.99)		9.77	0.245	2.77	
		9.97	0.234	2.65	
9.88	25.0	10.36	0.313	1.90	
(2.47)		10.64	0.310	1.88	
7.30	25.0	12.43	0.204	1.68	Leaf Test
(1.82)		10.66	0.283	2.32	
		10.99	0.262	2.15	
5.28	25.0	10.82	0.222	2.52	
(1.32)		11.40	0.220	2.50	
		11.92	0.159	1.81	Leaf Test
11.35	25.0	10.80	0.302	1.59	
(2.84)		10.67	0.305	1.61	
3.15	25.0	10.42	0.190	3.62	
(0.79)					

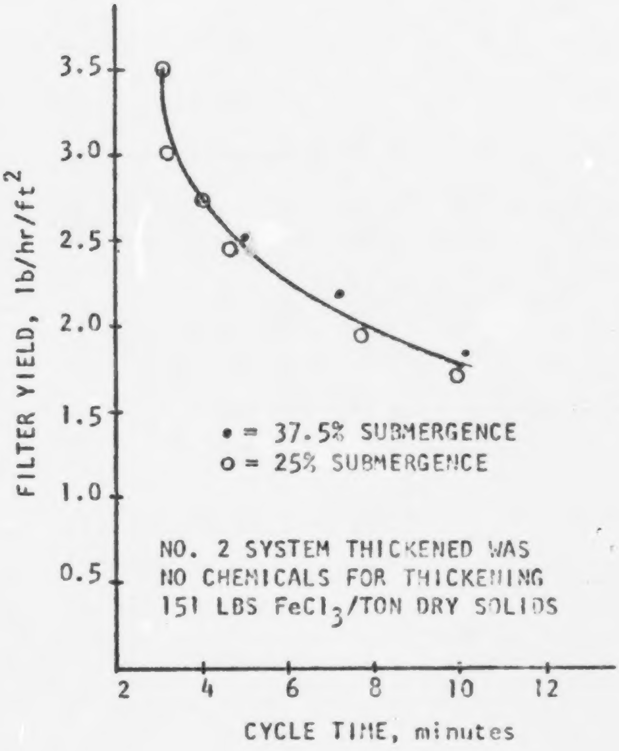


Figure 9. Filter yield vs. cycle time

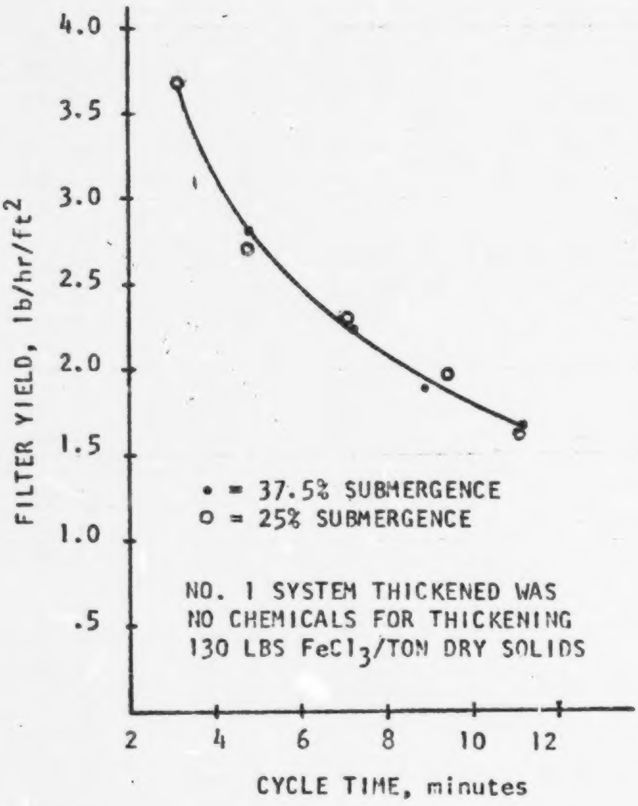


Figure 10. Filter yield vs. cycle time

Table 30. VACUUM FILTER OPERATION
OCTOBER 26, 1972

Sludge: No. 1 system waste activated sludge thickened with chemicals
Sludge solids: 2.40% total solids
Chemical dosage: 129 lb $FeCl_3$/ton dry solids

Cycle time (pickup time), min	Submergence, %	Cake solids, %	Loading, lb/ft^2	Yield, lb/hr/ft^2	
11.77	37.5	10.94	0.227	1.16	
(4.41)		10.89	0.235	1.20	
9.47	37.5	11.05	0.208	1.32	
(3.55)		11.33	0.212	1.34	
7.65	37.5	11.49	0.193	1.51	
(2.87)		11.25	0.193	1.52	
		10.48	0.185	1.45	Leaf Test
5.05	37.5	10.36	0.158	1.88	
(1.89)		11.16	0.151	1.80	
		10.51	0.175	2.08	Leaf Test
3.05	37.5	10.03	0.125	2.46	
(1.14)		10.08	0.127	2.50	
		9.67	0.140	2.75	Leaf Test
3.05	25.0	11.62	0.116	2.27	
(0.76)		11.02	0.122	2.40	
		10.98	0.127	2.50	Leaf Test
5.23	25.0	12.71	0.133	1.53	
(1.31)		11.99	0.132	1.51	
		11.81	0.138	1.58	Leaf Test
7.58	25.0	11.84	0.171	1.36	
(1.90)		12.49	0.161	1.28	
		12.65	0.156	1.24	Leaf Test
9.50	25.0	12.78	0.178	1.12	
(2.38)		12.76	0.177	1.12	
11.23	25.0	12.34	0.188	1.00	
(2.81)		12.50	0.185	0.99	

Table 31. VACUUM FILTER OPERATION
OCTOBER 30, 1972

Sludge: #2 system waste activated sludge thickened with chemicals.
Sludge solids: 2.71% total solids
Chemical dosage: 145 lb/ton

Cycle time (Pickup time), min	Submergence, %	Cake solids, %	Loading, lb/ft^2	lb/hr/ft^2	
7.52	25.0	10.85	0.131	1.04	Leaf test
(1.88)		8.50	0.222	1.77	
		8.63	0.212	1.69	
5.27	25.0	9.07	0.147	1.68	Leaf test
(1.32)		8.53	0.185	2.11	
		8.19	0.198	2.26	
9.60	25.0	8.47	0.227	1.42	
(2.40)		9.07	0.220	1.38	
7.62	37.5	10.30	0.131	1.03	Leaf test
(2.86)		8.15	0.232	1.82	
		8.11	0.238	1.88	
5.03	37.5	9.01	0.166	1.98	Leaf test
(1.89)		7.58	0.198	2.37	
		7.80	0.214	2.55	

No special significance is attached to the difference noted as the difference is attributed to the consistently higher solids loading (cake thickeness) associated with the filtration of System #1 sludge (See Tables 30 a 31) rather than to any difference in C/N ratio.

Comparison of Tables 30 and 31 shows that appreciably fewer tests were performed on System #2 sludge (Table 31) than on System #1 sludge (Table 30). The number of tests on System #2 sludge were curtailed because the remaining project funds were diminishing rapidly.

Filter yield versus cycle time data obtained from Tables 30 and 31 are plotted in Figures 11 and 12 for System #2 and System #1 sludges, respectively. Examination of Figures 11 and 12 shows a significant difference in the relationships obtained for the submergences investigated. These differences as well as the differences obtained in comparing the data in Figures 11 and 12 are again attributed to differences in solids loading (cake thickness) and/or cake solids content rather than in differences in the C/N ratio associated with the two systems.

The overall conclusion drawn from the filtration tests performed at the conditions investigated (#1 C/N = 70.5; #2 C/N = 45.3) are that the filtration characteristics of the waste sludges from the two systems are similar and comparable. The difference in C/N between the systems did not appear to have any effect on the filtration characteristics of the system sludges tested. The fact that both systems were grossly nitrogen nutrient deficient is indicated to be the overriding factor for the conclusion drawn.

Immediately after the last filtration test performed (10/30/73) and in the face of project termination due to impending exhaustion of project funds, operational changes were made to decrease the C/N ratio in System #1 from about 70.5 to

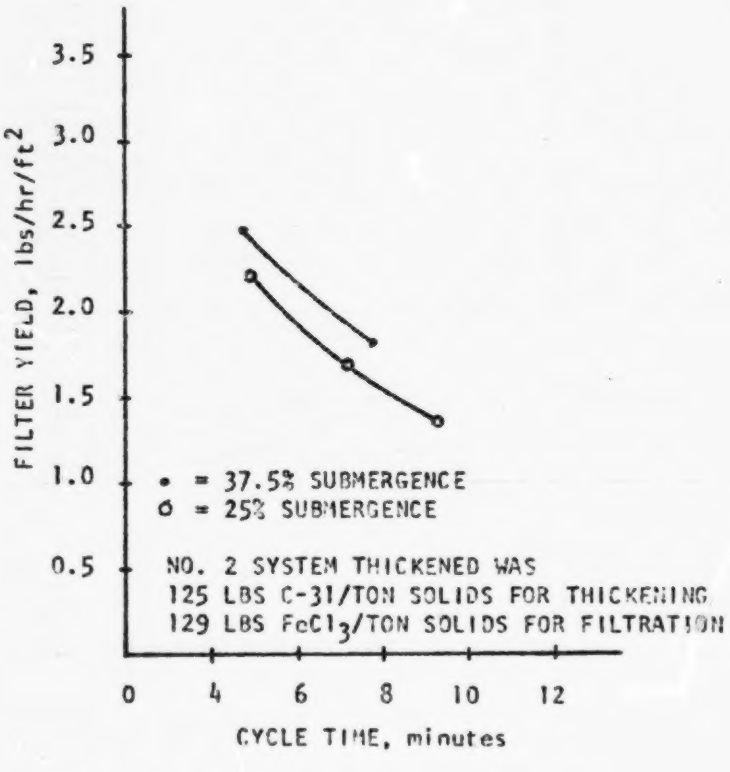
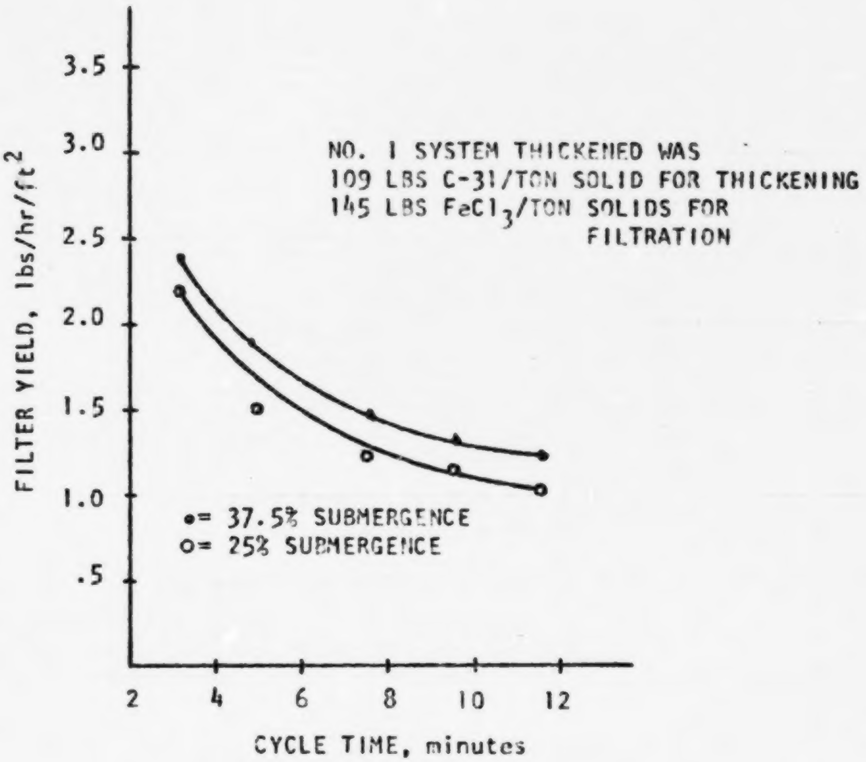


Figure 11. Filter yield vs. cycle time



NO. I SYSTEM THICKENED WAS
109 LBS C-31/TON SOLID FOR THICKENING
145 LBS $FeCl_3$/TON SOLIDS FOR
FILTRATION

Figure 12. Filter yield vs. cycle time

about 16 and to maintain the C/N ratio of System #2 at about 30. This was accomplished by simply increasing the amount of ammonia addition to System #1.

After making the operational C/N change described above, monitoring of the two systems was initiated on 11/1/72 and terminated on 11/9/72 because of insufficient funds to continue the project. The data obtained during the monitoring period investigated are presented in Table 32 for both systems. The parameters shown in Table 32 include C/N ratio, settling rates (unstirred and stirred), SVI, and % N.

Several pertinent observations may be made regarding the November 1972 data for System #1 (Test System) and System #2 (Control System) shown in Table 32.

1. The C/N ratios for the two systems were significantly different. The average C/N ratio for System #1 was 15 and that for System #2 was 29.
2. Both systems were nitrogen nutrient sufficient as indicated by the %N data. This represented a marked change from previous observations (see Tables 9, 10, 21 and 22). The average % N for System #1 was 7.4 and that for System #2 was 7.8. The magnitude of % N for System #1 may have been expected because of the additional ammonia added to System #1, but the magnitude of % N observed for System #2 was a total surprise, and explanation for this observation is not readily available.
3. The settling rate data, both stirred and unstirred, for the two systems were markedly different, with System #1 having appreciably higher settling rates than System #2. For example, from Table 32, the average settling rates (unstirred and stirred, respectively) for System #1 were 15.1 and 17.2 ft/hr whereas those for System #2 were

Table 32. NOVEMBER 1972 TEST DATA

Date	C/N Ratio		% N	
	System #1	System #2	System #1	System #2
11/1/72	--	36	5.70	7.43
11/2/72	16	30	4.18	6.89
11/3/72	17	32	8.15	7.94
11/6/72	10	14	8.91	7.65
11/7/72	17	33	9.12	8.69
11/8/72	18	36	9.19	7.98
11/9/72	13	23	6.27	7.86

Date	Solids settling rate, ft/hr				SVI	
	System No. 1		System No. 2		System No. 1	System No. 2
	Unstirred	Stirred	Unstirred	Stirred		
11/1/72	19.46	21.0	0.7	8.5	164	463
11/2/72	7.64	12.1	1.3	12.8	224	473
11/3/72	8.34	14.9	4.2	10.7	218	359
11/6/72	14.40	15.6	1.9	8.2	260	476
11/7/72	19.30	20.2	1.2	5.7	230	526
11/8/72	19.40	18.5	2.0	7.8	224	471
11/9/72	16.90	17.8	0.8	7.1	220	730

1.7 and 8.8 ft/hr. Moreover, it may be noted that in System #1 (see Table 32) the unstirred settling rate closely approached the stirred settling rate whereas under previous conditions (see Tables 9, 10, 21, and 22) there was an appreciable disparity between the two. The favorable trend observed is attributed to the beneficial change in the C/N ratio in System #1 and/or the nitrogen sufficiency of System #1.

On the other hand, for System #2, the unstirred and stirred settling rates were appreciably different (see Tables 32) and of the same magnitude as those observed under previous conditions (see Tables 9, 10, 21, and 22). These observations cannot be attributed to nitrogen deficiency as the % N data has indicated that System #2 was nitrogen sufficient (Table 32).

The above described observations and comparisons indicate that the favorable trend observed in the solids settling rates for System #1 is attributable to the favorable change in C/N ratio made in System #1.

4. Similarly, the SVI data for the two systems were markedly different, with System #1 having appreciably lower SVI's than System #2. For example, the average SVI for System #1 was 223 whereas that for System #2 was 498. Moreover, the average SVI for System #1 was appreciably lower than that observed under previous conditions (see Tables 9, 10, 21, and 22), and this favorable trend is attributed to the beneficial change in the C/N ratio in System #1 and/or the nitrogen sufficiency of System #1.

On the other hand, for System #2, the average SVI (see Table 32) was of the same order of magnitude as those observed under previous conditions, for the % N data (Table 32) has indicated that System #2 was nitrogen sufficient.

Again, the above described observations and comparisons indicate that the favorable trend observed in the SVI for System #1 is attributable to the favorable change in C/N ratio made in System #1.

Closure

The limited data obtained and presented in Table 32 and the discussion of that data have indicated that the threshold for achieving the project objectives had been reached. More extensive monitoring to supplement the data in Table 32 and further pilot plant thickening and vacuum filtration work were not carried out because the project funds to do so had been exhausted. Attempts by the project officer and by other concerned parties to obtain additional financial support of the project were unsuccessful. Therefore, because of the inability to find financial support for the study program, the project was terminated.

SECTION VIII

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